The Elementary Principles of Wireless Telegraphy

by

R. D. Bangay

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THE ELEMENTARY PRINCIPLES OF WIRELESS TELEGRAPHY

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[Part I]

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PREFACE TO FIRST EDITION

In presenting this Handbook, the author has endeavoured to explain, in the simplest possible manner, the theory and practice of Wireless Telegraphy.

It has been his aim to make the subject intelligible to persons who do not possess much technical knowledge, and to be at the same time brief and accurate.

The book has been so arranged as to be useful as a reference book on the subject for students and amateurs in this special branch of electrical science.

Further and more complete explanations of the various phenomena described can be obtained from the standard scientific works on the subject, but it has been the object of the author to deal with the subject clearly and simply without going too deeply into the many highly technical problems involved.

R. D. B.

PREFACE TO SECOND EDITION

WITH the object of increasing the usefulness of this Handbook, the author has extended its scope without going any more deeply into the technical side of the subject.

Since the book has been used largely in the training of Telegraphists who are frequently called upon to take sole charge of complete Wireless Telegraph Installations, the author has endeavoured to cover all parts of the transmitting and receiving apparatus in such a way as to give the student a sound working knowledge of the apparatus entrusted to his care.

For the convenience of the student, the new edition is divided into two parts. Part I. contains, in addition to the matter published in the first edition, and now revised, a good deal of further information regarding Receivers and Aerials. In Part II. the component parts of a Transmitter are explained separately, and the theory of the condition of resonance under which they can most effectively be combined, and to which each part should be adjusted to form an efficient transmitter, is fully discussed.

R. D B.

CONTENTS

The European or Continental Morse Code

a	·—	m	——	z	——··
à	·—·—	n	—·		
á or å	·——·—	ñ	——·——		
b	—···	o	———		
c	—·—·	ö	———·		
ch	————	p	·——·		
d	—··	q	——·—		
e	·	r	·—·		
é	··—··	s	···		
f	··—·	t	—		
g	——·	u	··—		
h	····	ü	··——		
i	··	v	···—		
j	·———	w	·——		
k	—·—	x	—··—		
l	·—··	y	—·——		

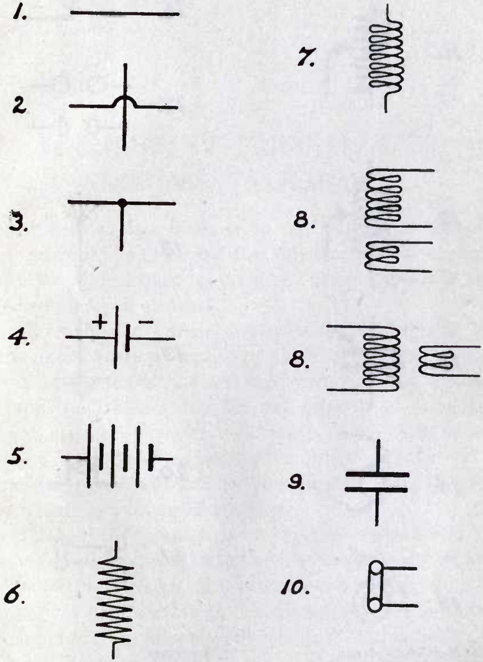
Numerals.

1	·————
2	··———
3	···——
4	····—
5	·····
6	—····
7	——···
8	———··
9	————·
0	—————

Punctuation Marks

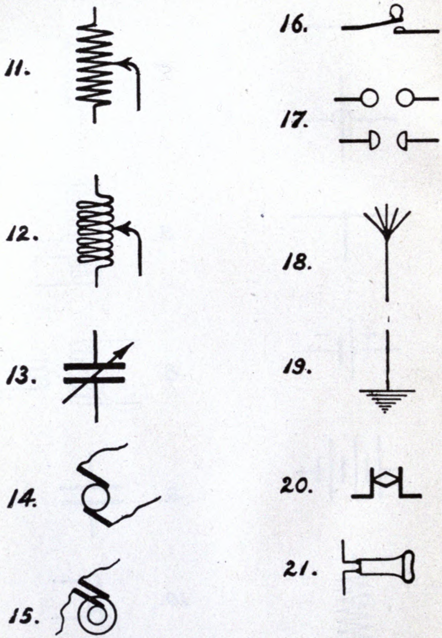
	······	“ ”	·—··—·
?	··——··	;	—·—·—·
!	——··——	,	·—·—·—

SYMBOLS USED IN DIAGRAMS OF WIRELESS TELEGRAPHY CIRCUITS



1. Conductor.
2. Conductors crossing.
3. Conductors connected.
4. Cell.
5. Battery.
6. Resistance coil.
7. Inductive winding.
8. Two coils having mutual inductance.
9. Condenser.
10. Switch.

SYMBOLS USED IN DIAGRAMS OF WIRELESS TELEGRAPHY CIRCUITS



11. Variable resistance.
12. Variable inductance.
13. Variable condenser.
14. Direct current dynamo.
15. Alternating current dynamo.
16. Manipulating key.
17. Spark-gap.
18. Aerial wire or antenna.
19. Earth connection.
20 Crystal detector.
21. Telephone receiver.

ELEMENTARY PRINCIPLES OF WIRELESS TELEGRAPHY

THE object of this book is to instruct the reader in the principles underlying the construction of modern Wireless Telegraphy apparatus, more especially as applied to small stations.

Although the same principles apply equally to commercial stations having a range of communication up to thousands of miles, it is obvious that the method of applying these principles will depend to a certain extent upon the size of the station. Thus factors which require important consideration when dealing with powerful plant will fall to comparative insignificance when dealing with small stations.

Wireless Telegraphy is a special application of electrical phenomena, therefore an elementary knowledge of the subject of electricity and magnetism is absolutely essential before full advantage can be taken of a study of the principles of Wireless Telegraphy.

This book is written on the assumption that an elementary knowledge of electricity and magnetism is possessed by the reader, but in order to assist the uninitiated, and for the purpose of reference, we have, in the first part of the book, briefly described the

various points of importance, but the information given should be supplemented by a study of any of the standard text-books on the subject

Electricity is the name given to that which causes all electrical phenomena.

Electricity is invisible and intangible, although both visible and tangible effects can be produced by it. Its exact nature, therefore, can only be imagined, but its effect upon matter has been carefully studied, and from the study and classification of these phenomena the laws governing the effects of electricity have been deduced.

Perhaps the best view-point to take is to consider electricity as an agent or medium by which work or energy can be transmitted from one point to another.

For instance, let us take, as an example, an electric-power installation In one building we have an engine driving a dynamo, and in another building, which may be far removed, we have an electric motor driving, say, a circular saw used for cutting wood.

Energy is put into the boiler of the engine in the form of heat by burning coal. The boiler converts this heat energy into steam pressure carried along pipes to the engine, where in turn it is converted by the engine and dynamo into electrical energy. The electrical energy is carried along wires to the motor in the other building, and the motor converts the electrical energy into mechanical energy by turning a circular saw, and the energy is then used to cut through wood.

Now it is not the electricity which cuts the wood, but the energy which is put into the boiler of the engine. Electricity is simply a convenient agent by which that

energy can be transferred from the boiler-room to the work-room.

It is on account of the fact that by this agency energy can be transferred conveniently and cheaply over a great or small distance, and can by means of suitable apparatus be converted into almost any desired form of energy—such, for example, as light, heat, motive power, etc.—that electricity is so extensively used for all purposes.

ELECTRICITY AND MAGNETISM

1. When a charge of electricity rests on the surface of any substance, such as amber, glass, etc., the charge of electricity is known as a static charge, and the study of the effects of these charges is known as **electro-statics.**

2. When a charge of electricity passes through a substance, such as copper, silver, etc., the charge is known as an electric current, and the study of the effects of these currents is known as **electro-dynamics.**

Electro-statics

3. If we take a piece of amber and rub it with a piece of silk, we find that the amber has acquired the property of attracting very light objects, such as fragments of paper, cork, cotton-wool, or pith balls, and that if these objects actually touch the amber which is attracting them, they are then repelled.

These attractions and repulsions are due to a **static charge** of electricity, which has been generated by the

friction with the silk, and which is resting on the surface of the amber.

4. If then, for convenience, we suspend a small pith ball by a silk thread, as shown in Fig. 1, and approach it with an electrified amber rod, we shall see that the pith ball **will first fly towards the rod, and that immediately it touches the rod it will be repelled.**

5. This is because by contact with the rod the pith ball has itself become charged, and as long as both the pith ball and the amber rod retain their charges, repulsion will take place whenever they are brought near each other.

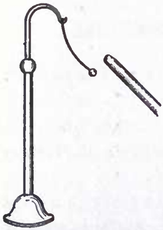


Fig. 1.

6. If, now, instead of electrifying an amber rod with a piece of silk, we electrify a piece of sealing-wax by rubbing it with a piece of flannel or fur, and we approach the already electrified pith ball with the electrified sealing-wax, we find that instead of repelling the ball as the electrified amber rod does, it attracts it, although as soon as they come in contact with each other the pith ball is again repelled, and after being repelled by the electrified sealing-wax will once more be attracted by the electrified amber.

7. When this simple experiment is analysed, it is found that there are two kinds of electrification—one produced by rubbing amber with silk, and the other produced by rubbing sealing-wax with fur.

8. In order to distinguish between the two, that produced by rubbing amber with silk is called a **positive charge** (+), and that produced by rubbing sealing-wax with fur is called a **negative charge** (−).

9. By simple experiments it can be shown that **neither charge is ever produced alone,** for when amber is rubbed with silk, although a positive charge is produced on the amber, an equal negative charge is produced at the same time on the silk, and *vice versa* when sealing-wax is rubbed with fur.

10. From these and other similar experiments the following laws may be deduced :

(1) *That when either a positive or a negative charge is produced, an equal and opposite charge is also produced.*

(2) *That like charges repel one another, and unlike charges attract one another.*

(3) *That when an electrified body touches an unelectrified body, the latter becomes charged to the same "polarity" as the former.*

(4) *That when an electrified body touches an oppositely electrified body, if the two charges are equal their electrification is destroyed, and they are then said to be discharged ; but if the charge on one body is greater than that on the other, their electrification is only partially destroyed, and both bodies become charged to the same polarity as that of the greater charge.*

Conductors and Insulators

11. The bodies which we have been electrifying do not conduct electricity, but they resist or oppose the passage of electricity through them, and it is for this reason that the charge produced on them rests on their surface.

12. When a charge of electricity is applied to a metal, the electricity immediately flows through it, and for this reason metals are called **conductors of electricity.**

13. All metals are conductors, those most commonly used in electrical apparatus for this purpose being copper, brass, aluminium, iron, etc. To a much lesser extent the human body and water (except the purest distilled water) are conductors.

14. The substances which will not conduct electricity are called **insulators**, and for this purpose the chief materials used in electrical apparatus are amber, sealing-wax, glass, porcelain, ebonite, mica, silk, rubber, oils, dry wood, string, and cotton.

15. An important point to bear in mind is that none of the substances mentioned as conductors are perfect conductors; that is to say, none of them will carry a current of electricity without some loss of energy due to "friction" or "resistance" Some of them, however, are better conductors than others; for instance, copper is a better conductor than iron, and for this reason there is less loss of energy due to "resistance" in copper than in iron.

16. Similarly no substance is a perfect non-conductor, or insulator. There will always be some loss due to leakage, although by using a suitable material this leakage can be reduced to a negligible quantity.

Static Induction

17. When an electrified conductor is brought near another conductor which has not been electrified, an electric charge will be **induced** in the latter.

This effect is known as Static Induction.

18. The charge which is induced in the non-electrified conductor is not a permanent charge, but depends entirely for its existence upon its proximity to the

electrified conductor This is illustrated in Fig. 2, where A is a plate of metal which has been permanently charged by touching it with an electrified amber rod, and B is a similar plate of metal which has not been charged Both plates are supported by pillars of glass, or other insulating material, to prevent their charges being conducted to earth.

19. As A is brought nearer and nearer to B a stronger and stronger charge is induced in the latter, and as A is taken farther away from B the induced charge in B becomes weaker. All the time, however, the plate A retains the original charge which was given to it.

20. The range of space over which the electrified plate A has the power of inducing a charge in B is called the **Electro-static Field.**

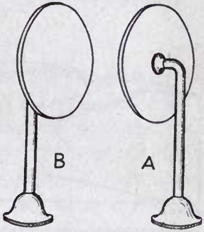


FIG. 2

21. If the two plates are brought together so that they touch one another, then the permanent charge in A flows into B, and the charge is divided equally between the two plates. The plate B will then retain this charge, even when taken away from the influence, or electrostatic field, of A.

22. We have said that the strength of the charge induced by an electrified conductor in another conductor depends upon the distance between the two. The strength of the charge also depends upon the nature of the substance between the two bodies, which must be a non-conductor.

This substance is called a **dielectric.**

23 **All dielectrics are non-conductors.**

24. The facility with which a dielectric allows static induction to act through it is called its **Inductive Capacity.**

If the space between the plates A and B is filled by glass, it is found that a much stronger charge is induced in B than when the same space is filled with air. Therefore we may say that the inductive capacity of glass is greater than the inductive capacity of air.

25: A simple mechanical analogy of these phenomena

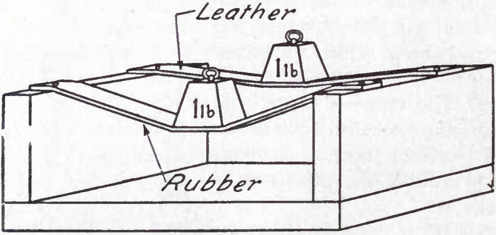


FIG. 3

can be made by comparing the **electrical inductive capacity** of a dielectric with the **mechanical extensibility** of a material.

If we stretch two pieces of different material, such as a strip of leather and a strip of rubber, each having an equal thickness, between two fixed points, as shown in Fig. 3, and we place on each of them a weight of, say, 1 lb., we find that the rubber stretches a great deal more than the leather, and therefore we say that the **extensibility of rubber is greater than that of leather,** just as we said that the **inductive capacity of glass was greater than that of air.**

26. The same analogy illustrates the effect of increasing the thickness of the dielectric; for if we increase the thickness of the rubber strip in the experiment just described, although we are using a material of the **same extensibility** as before, yet owing to the fact that it is thicker, the same weight will not **stretch** the rubber to the same extent as before. Similarly, if we increase the distance between the two plates A and B in Fig. 2, or, in other words, increase the thickness of the dielectric, the effect of the **static induction** is reduced, although the dielectric has the same Inductive Capacity as before.

The Condenser

27. Static Induction is the principle underlying the construction of a "condenser." A simple type of condenser consists of a plate of glass, or some other dielectric (*vide* paragraph 23), covered with tin-foil or other conductor on either side. The tin-foil merely acts as a means of distributing any applied electrical pressure uniformly over the surface of the dielectric.

28. The property a condenser has of holding a large or small charge of electricity is called its "**Capacity.**"

This property of capacity can best be illustrated by comparing it with the analogous mechanical property of springiness or flexibility.

29. If a mechanical force is applied to a spiral spring, the spring will be extended to a distance X, shown in Fig. 4, until it exerts a force exactly equal and opposite to the applied force. Similarly, if an electrical force (*vide* paragraph 36) be applied to a condenser, the dielectric of the condenser will be strained electrically until the condenser exerts an electrical pressure exactly equal and opposite to the force applied to it

30 Taking the mechanical case of a spring, it will be observed that a movement or an extension of the spring must take place before it exerts an opposite force, and further, that the amount of this movement, *i e* the distance X in Fig 4, which takes place for a given applied force, will depend upon the **flexibility** or springiness of the spring

31. Similarly, in the case of a condenser, owing to the straining of the dielectric, we get a certain amount of electricity forced into the condenser when an electrical pressure is applied to it A current of electricity must flow into the condenser before it exerts an opposite force, and further, *the quantity of electricity which flows into a condenser for a given applied force depends upon the capacity of that condenser*

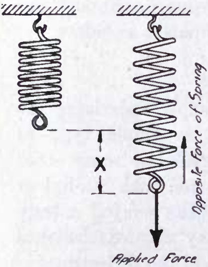


FIG. 4

32 An analogy which is perhaps easier to understand is shown in Fig 5, where a steel nozzle is shown, over the end of which is fastened a thin india-rubber cap, which under normal conditions will lie evenly across the end of the nozzle If now a pressure be applied to this india-rubber by connecting the nozzle to a water-tank the rubber will be bulged out by the pressure of the water, as shown in Fig. 6, until the rubber exerts a pressure on the water equal and opposite to the pressure exerted by the tank

Obviously the expansion or the bulging of the india-rubber allows it to contain a certain quantity of water when a force is applied to it so that we can say that,

owing to the stretching of the cap, a certain quantity of water will be forced into it, and the quantity of water which it will contain, for a given pressure, will depend upon the **flexibility** of the cap.

33. Similarly, if an electrical force be applied to a condenser, owing to the electrical straining of the dielectric of the condenser, a certain quantity of electricity will be forced into it, until the condenser exerts an electrical pressure equal and opposite to the pressure applied to it.

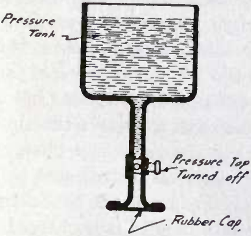


FIG. 5.

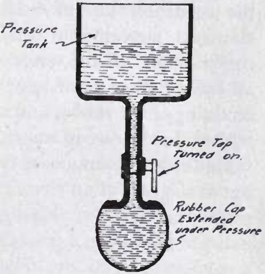


FIG. 6.

The quantity of electricity which will be forced into a condenser for a given applied pressure will depend upon the capacity of that condenser.

Thus we may say that the capacity of a condenser is analogous to the flexibility of the india-rubber cap, or, in the first experiment described, to the flexibility of the spring; and we can take the flow of electricity into a condenser as being analogous to the flow of water into the cap, or, in the first experiment described, to the movement of the spring.

34. Now just as the flexibility of the spring (or of the cap, as the case may be) depends upon three things,

namely, (1) the size of the spring (or cap) to begin with, *i.e.* its length and diameter, (2) the thinness of the material of which it is made, and (3) the mechanical extensibility of that material, so does the capacity of a condenser depend upon three analogous factors, namely, (1) the area of the plate forming the condenser, (2) the thinness of the dielectric, and (3) the inductive capacity of the dielectric.

35 **An important point to grasp is that the property the condenser has of holding electricity is due to the electrical straining of the dielectric** and not to any compression of the electricity, just as the property an india-rubber cap has of holding water is due to the straining of the rubber and not to any compression of the water. In the case of the rubber cap, this straining has a visible effect, inasmuch as it increases the size of the cap; but in the case of an electrical condenser no such obvious result can be seen, although electrical instruments will indicate that when a pressure is applied to the condenser a current of electricity flows into it until it is charged.

The effect of capacity in an electrical circuit is in all respects similar to the effect of a spring in a mechanical system, and the analogy is extremely helpful in studying the effects of capacity in circuits such as those used in Wireless Telegraph installations.

ELECTRO-DYNAMICS

36. An electric current is a **flow** of electricity.

In order to produce an electric current, it is first necessary to exert a difference of electrical pressure between two bodies, or between two parts of the same body. This **difference** of pressure is called the **Electromotive Force.**

37. In order that an electric current will flow, however, it is necessary that the body, or bodies, across which the difference of electrical pressure is exerted is a conductor of electricity.

Fig. 7.

A simple mechanical analogy can be made to illustrate this.

A long pipe, as shown in Fig. 7, is filled with water. The pipe represents a conductor, and the water illustrates the electricity in the conductor. Both ends of the pipe are held upwards on a level with one another, so that normally there is no difference in pressure acting at each end of the tube, and therefore the water will not flow through the tube.

If, however, we exert a pressure at one end of the pipe by blowing down it, or by increasing the height

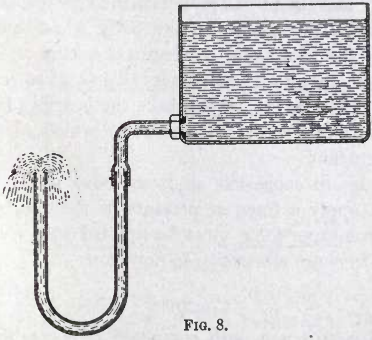


Fig. 8.

of one end above the other, or, better still, by connecting a tank of water to it which is situated at a higher level than that on which the experiment is being carried out,

as shown in Fig. 8, then the water will immediately flow through the pipe.

38 By connecting the tank to one end only of the pipe, we exert a difference of pressure on the two ends of the pipe, but if we connect the tank simultaneously to both ends of the pipe, then there is no difference of pressure on the two ends of the pipe, and consequently no water will flow through it.

39 As the water represents electricity, the flow of water represents an electric current (*vide* paragraph 36).

40. The analogy of water flowing through a pipe, although useful in some cases, is not a good one to take generally as representing the flow of electricity in a conductor, and it is apt to be very misleading, more especially when studying the effects of capacity and inductance It is much better to take the mechanical effect of "**movement**" to represent the flow of electricity, and to take the nature of the body which moves to represent the features of an electrical circuit.

Thus, if we take the movement of a shaft to represent the flow of electricity, we can take the bearings in which it moves to represent the conductor which carries the electric current

In order to cause the shaft to move in its bearing we must apply a force or pressure to the shaft just as an electromotive force must be applied to a conductor in order to cause electricity to flow in it.

Circuits

41. A circuit is a path composed of a conductor, or conductors, through which an electric current flows from one point in it around the conducting path back to the point from which it started.

An electric source, such as a battery, or dynamo, is generally included in a circuit, the function of the electric source being to produce a **difference in pressure** or an **electromotive** force in the circuit.

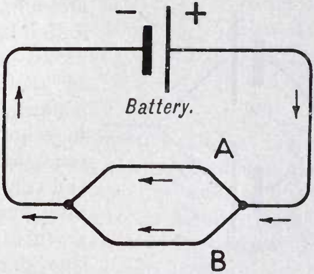


Fig. 9.

42. Different parts of a circuit can be connected in parallel or in series.

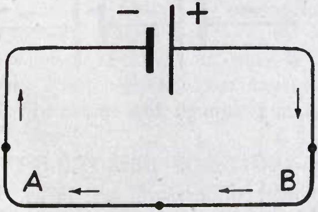


Fig. 10.

43. Thus, when two conductors A and B are joined in a circuit as shown in Fig. 9, they are said to be joined in parallel, or if they are joined as shown in Fig. 10, they are said to be joined in series.

44. When conductors are joined in parallel, only part

of the total current flows through each conductor. When they are joined in series, the whole current passes through each conductor successively.

45. When two cells (a cell is a source of electric pressure, and is described later) are connected in a circuit, as shown diagrammatically in Fig. 11, they are said to be connected in parallel, and only part of the total current in the circuit will flow through each cell.

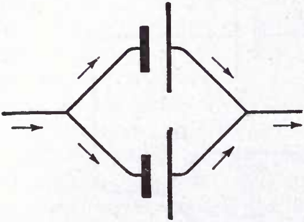


FIG. 11.

46. When they are connected, as shown in Fig. 12, they are said to be connected in series, and the whole

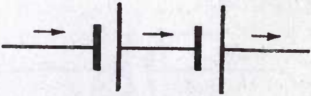


FIG. 12.

current passing through the circuit will flow through each cell.

UNITS OF ELECTRICITY

47. In order to measure and define the different electrical factors of a circuit, certain practical standards, or **units**, have been adopted.

It is not necessary for the purpose of this book to explain how these units have been arrived at. It is sufficient to describe the particular quality, or property, which each represents and the relation which one bears to another.

48. The unit of	quantity	is	one Coulomb.
,, ,,	current	,,	one Ampere.
,, ,,	electromotive force or pressure	,,	one Volt.
,, ,,	resistance	,,	one Ohm.
,, ,,	inductance	,,	one Henry.
,, ,,	capacity	,,	one Farad.
,, ,,	energy	,,	one Joule.
,, ,,	power	,,	one Watt.

The Coulomb

50. The Coulomb is the electrical unit of quantity, and can be compared with the water unit of quantity, namely, "a gallon," or, better, with the mechanical unit of rotary motion, namely, "one revolution" (*vide* paragraph 40).

The Ampere

51. The Ampere is the electrical unit of current.

When a current of water flows through a pipe, the amount of flow can be defined by stating how many "gallons per second" are flowing.

Similarly in an electrical circuit, when a current of electricity flows through a conductor, the rate of flow can be defined by stating how many coulombs per second are flowing.

Again, when a shaft rotates in a bearing the amount of rotation or "speed" can be defined by stating how many revolutions per second it is making, and in this case one revolution per second is the unit of speed.

52. In an electrical circuit one "**ampere**" **represents a flow of one coulomb of electricity per second.**

The Volt

53. The Volt is the unit of electrical pressure,

variously described as "difference of potential," or "electromotive force" (E.M.F.).

54. It can be compared with the practical unit of mechanical force, namely, the pound.

The flow of water, that is, the number of gallons per hour that will flow through a pipe of given length, size, and shape, will depend upon the number of pounds of pressure applied at one end of the pipe, or to put it more correctly, upon the difference in the number of pounds acting on the two ends of the pipe.

Again, the speed at which a shaft will rotate in a given bearing will depend upon the twisting force or "torque" applied to the shaft.

55. Similarly, the flow of electricity, **or the number of amperes that will flow through a conductor of given length, size, and shape, will depend upon the difference in the number of volts acting at each end of the conductor.**

The Ohm

56. The Ohm is the unit of resistance.

57. Resistance can be compared with the mechanical property of friction, for example, with the friction between the water and the inside of a pipe when the water is flowing through the pipe, or the friction between a shaft and its bearings.

58. Just as friction opposes the flow of water through a pipe or the rotation of the shaft, so does **resistance oppose the flow of electricity through a conductor.**

59. *A conductor having a resistance of one ohm will require an electromotive force of one volt to force a current of one ampere through it.*

The Henry

60. The Henry is the unit of inductance.

61. **Inductance is that quality in a circuit which tends to oppose any change in the flow of electricity.** It must not be confused with "resistance," which opposes the flow of electricity.

62. It can best be described by comparison with the mechanical property of mass, as its effect in an electrical circuit is analogous to the effect of the inertia and momentum of a heavy body in motion.

All bodies when stationary show a tendency to oppose being put in motion, or if they are already in motion, to oppose being accelerated. This tendency is called "inertia." Similarly, all bodies when in motion show a tendency to oppose being stopped, or having their speed reduced. This tendency is called "momentum."

63. It is well known that it takes a considerable time for an engine with a heavy fly-wheel to get up full speed. This is due to the inertia of the fly-wheel. Also an engine running at full speed takes a considerable time to be brought to a standstill. This is due to the momentum of the fly-wheel.

64. In the same way there is a tendency in a circuit to oppose any increase, or decrease, in the current flowing through it. This quality is called Inductance.

If an E.M.F. be applied to a circuit possessing inductance, the current flowing as a result of the E.M.F. will only gradually grow, and the greater the inductance the slower the rate of growth. Again, if, when the current is flowing through a circuit possessing inductance, the E.M.F. which is making it flow be suddenly removed, the current will only gradually stop flowing, unless of course the circuit be "broken" or interrupted.

Thus it will be seen that the effect of inductance in a circuit on any current flowing through it is exactly

similar to the effect of inertia in a body on any movement of that body.

65. Inductance is really due to the magnetic field produced by the current in a circuit (see paragraph 85), and the amount of the inductance depends upon the strength of the magnetic field thus produced, just as the amount of the inertia, or momentum, of a fly-wheel depends upon the weight of that fly-wheel.

66. It will be shown later that the amount of magnetic field produced by a circuit, and therefore **the inductance of a circuit, depends upon its form**; for instance, the inductance of a given length of wire will be far greater if that wire is wound into a coil than if it is stretched out straight.

Similarly, the momentum of a fly-wheel depends upon its shape as well as its weight. thus a fly-wheel two feet in diameter, weighing ten pounds, will have a very much greater momentum or inertia than a fly-wheel one foot in diameter, also weighing ten pounds

67. One great difference between the effect of resistance and that of inductance in a circuit is that **resistance absorbs energy** and dissipates it in the form of heat, just as friction absorbs mechanical energy and dissipates it in the form of heat, whereas **inductance only stores up energy when the current is increasing, and gives its energy back when the current is decreasing**, just as a fly-wheel stores up energy when its speed is increased and gives back its energy when the speed is decreased.

When a circuit has an inductance of one henry, the current flowing through that circuit will change by one ampere when a difference of potential of one volt has been applied for one second

The **microhenry** is sometimes used as a more con-

venient unit when the circuits under consideration have very small inductances. One microhenry is one-millionth part of a henry.

The Farad

68. The Farad is the unit of capacity.

69. We have already described in paragraph 28 that capacity is the property which a condenser has of holding a certain quantity of electricity, and we compared this property with the mechanical flexibility of a spring

If we take the amount in inches that a spring will extend when a given force of one pound is applied to it as being a measure of its flexibility, we could specify this quality of any spring by stating how many inches or what fraction of an inch theoretically it would expand for this given pressure. Thus by coining a word, "pound-inch," we could say that if a spring was such that it would expand one inch when one pound of pressure was applied to it, it has a flexibility of one " pound-inch."

70. Similarly, the electrical unit of capacity is a measure of the quantity of electricity which will flow into a condenser when a pressure of one volt is applied to it. *Thus if a condenser be of such dimensions that it will hold one coulomb of electricity when a pressure of one volt is applied across it, it will have a capacity of one " Farad."*

71. A condenser sufficiently large to hold a charge of one coulomb of electricity at a pressure of one volt would have to be of enormous dimensions, and therefore a farad is too large a unit for practical convenience, and the **microfarad** is therefore usually adopted in its place, a microfarad being one-millionth part of a farad

72 **An important point to grasp is that although energy is expended in charging up a condenser, this**

energy is in reality only stored up by the condenser, and is available for use by discharging that condenser through a useful channel; just as in the case of a spring although energy is expended in expanding or compressing a spring, that energy is only stored up by the spring, and is available for use by discharging the spring in a useful way. For example, take the case of an air-gun energy is stored in the gun by compressing a spring, and this energy is then available for driving a shot against the friction of the air when the spring is released

Later on in this book we shall show many examples of how energy stored up in a condenser is made to do useful work by discharging that condenser through suitable circuits.

The Joule

73. The Joule is the practical unit of electrical energy or work

In order to cause a current of electricity to flow in a circuit, energy or work must be expended.

The same rule applies to all matter For example, in order to cause a body to move, energy or work must be expended The mechanical unit of work is the "foot-pound," and can be defined as follows

If a force of one pound is used to move a body, the amount of work expended in moving that body a distance of one foot is one **foot-pound.** For instance one foot-pound of energy is expended in lifting a body weighing one pound a foot off the ground, because the force of one pound is being exerted on it throughout the distance it is being lifted

The electrical unit of work is, as we have already stated, the joule, and can be defined as follows .

74. *If a force of one volt is used to cause an electric current to flow through a circuit, one joule of work has been expended when one coulomb of electricity has flowed.*

From this definition of a joule in terms of quantity and pressure, it follows from the fact that one ampere of current is one coulomb per second, that a joule is also the amount of energy expended during one second of time in causing one ampere to flow through a resistance of one ohm (*vide* paragraph 59).

The Watt

75. The Watt is the electrical unit of power. Power is the work done per unit time, or the rate of doing work. One watt is the power required to do one joule of work per second.

76. Now, since a flow of one coulomb per second is one ampere, it follows from the definition of a joule that one watt of power is expended when one volt is used to cause a current of one ampere to flow. This can be expressed as an equation :

$$\text{Watts} = \text{Volts} \times \text{Amperes}.$$

For convenience the Kilo-watt (KW) is often used as the unit of electrical power instead of the watt ; one kilo-watt equals 1000 watts.

Example.—If a force of 10 volts causes a current of 100 amperes to flow through a given circuit, the power expended in this circuit :

$$= 10 \times 100 = 1000 \text{ Watts or } 1 \text{ KW}.$$

Ohm's Law

77. In every electrical circuit there are particularly three factors, the true relation of which must be clearly understood.

These three factors are **the force or pressure, the current**, and **the resistance**, and, as already explained, are measured in terms of volts, amperes, and ohms, respectively.

They bear a definite relation to one another, which is expressed by Ohm's Law.

78. **Ohm's Law.**—*The strength of the current flowing through any circuit is directly proportional to the pressure acting across the circuit and inversely proportional to the resistance of the circuit.*

In other words, the current is equal to the pressure divided by the resistance.

Using the units which are a measure of these factors, the law can be stated as an equation thus:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

and therefore by transposing,

$$\text{Volts} = \text{Amperes} \times \text{Ohms}$$

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}.$$

Example.—If a pressure of 6 volts be applied to a circuit whose resistance is 3 ohms, then the current flowing through that circuit will be 2 amperes, thus:

$$\text{Amperes} = \tfrac{6}{3} = 2.$$

MAGNETISM

79. Magnetism is the name given to the power which a magnet has of attracting iron or other magnetic substances.

The lodestone is a natural magnet, and if a piece of hard steel is rubbed by it, or by another magnet, it will

be found to act in the same way as the natural magnet itself; that is to say, it will point north and south when freely suspended, and will attract iron filings.

The piece of steel is then said to be magnetised, and is known as a *permanent magnet.* One end of the magnet is called the North (N.) Pole, and the other the South (S.) Pole.

80. The range, or space, over which a magnet will attract other magnetic substances is called the "**magnetic field.**"

81. If the North Pole of one magnet is brought near the South Pole of another magnet, the two will attract one another, but if the two North Poles or two South Poles are brought near one another, they repel each other.

It can be said, therefore, *that like poles repel and unlike poles attract one another.*

82. **Magnetic effects act in a definite direction along imaginary lines, called "lines of force."**

Every line of force passes out from the North Pole round a complete circuit, and returns into the South Pole, as shown in Fig. 13.

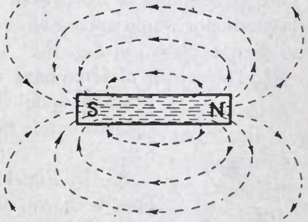


FIG. 13.

83. When a magnetic substance is brought into a magnetic field, the substance becomes magnetised.

This effect is called "magnetic induction."

For the purpose of this book it is not necessary to go fully into the factors controlling magnetic force,

or the units by which these factors are measured, but it is essential that the relation, or connection, between electricity and magnetism is thoroughly understood.

84. The study of the relation between electricity and magnetism is called " electro-magnetism."

Electro-magnetism

85. **A current of electricity passing through a conductor produces a magnetic field round that conductor,**

Fig. 14

the lines of force forming the magnetic field being a number of concentric circles with the conductor as their centre.

86. If the lines of force were visible, a side view of the conductor would appear as shown in Fig. 14, and an end view as shown in Fig. 15.

87. These lines of force **have a definite direction** depending upon the direction in which the current is flowing (*vide* paragraph 82).

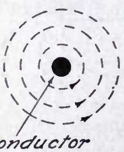


Fig. 15.

88. In Fig. 15 the direction of the lines is shown, assuming that the current is flowing in the conductor upwards towards the reader. If the current were reversed, the direction of the lines of force would be reversed, although they would still remain as concentric circles.

89. If the conductor is bent into a circle, as shown in Fig. 16, and the current is passed through it in the direction shown by the large arrows, it will be seen that the magnetic lines are all acting in an upward direction on the inside of the circle of wire, and in a downward direction on the outside of the circle. The field thus produced is exactly similar to that produced by a magnet, for it has polarity.

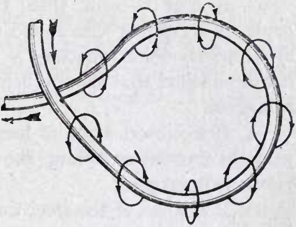


Fig. 16.

90. Since the lines of force come out of the upper side of the circle and go in at the under side of the circle, the upper side becomes the North Pole and the lower side becomes the South Pole.

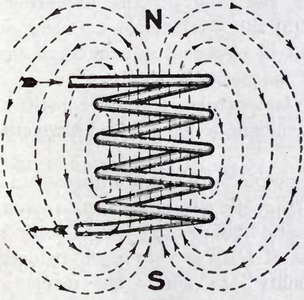


Fig. 17.

91. This effect is still more marked if, instead of making only one turn of the wire, we make a coil of wire, as shown in Fig. 17.

92. In this case the lines of force produced by each turn, instead of acting right round the conductor, can be imagined to combine with those produced by the

next turn, thus giving the resultant effect shown in Fig. 17.

93. It may be said, then, that if a straight coil is made by wrapping wire round a bobbin, and a current of electricity from a battery is passed through the coil, it will be found that the coil behaves exactly as if it were a magnet.

94. If we insert a rod of hard steel into the coil and pass the current as before, the steel rod will become a permanent magnet.

95. If instead of the steel we insert a rod of soft iron into the coil, it also becomes a magnet, but it is only magnetic so long as the current lasts. This is called an **electro-magnet.**

96. It is found that the **strength of the magnetic field** produced depends upon three factors: (1) **the current** passing round the coil, (2) **the number of turns** in the coil, and (3) the "**reluctance**" (which is the magnetic equivalent of electrical resistance) of the "magnetic path" or "magnetic circuit."

The first two of these factors taken together constitute the force-producing magnetism, which is called **Magneto-motive Force.**

The unit of magnetomotive force is one ampere-turn.

97. If we place any magnetic substance, such as iron, in the path of the magnetic lines of force, the reluctance of the path of the lines of force is very much reduced because the "**permeability**" (which is the magnetic equivalent of electrical "conductivity") of iron is very much greater than that of air, with the result that the strength of the magnetic field, or, in other words, the total number of magnetic lines of force, produced by the same current passing through the coil, is very much increased

Electro-magnetic Induction

98. As a magnet is made to enter a coil of wire, an electromotive force is induced in the coil of wire, so that if the electrical circuit be completed by connecting the two ends of the coil together, a current of electricity will flow through the coil.

This effect is known as **Electro-magnetic Induction.**

99. If a galvanometer or other suitable measuring instrument be connected between the ends of the coil, as shown in Fig. 18, so that any current flowing through the coil will flow through the instrument, the deflection of the pointer will indicate roughly the amount of current flowing through the coil, and the direction in which it is flowing.

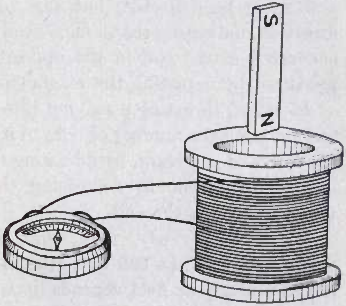


Fig. 18.

100. **If now a magnet be thrust into the coil**, the needle of the galvanometer will be deflected from its normal position, indicating that a current of electricity has been generated in the coil.

101. **If the magnet be left lying inside the coil**, the needle of the galvanometer will return to its normal position, thus indicating that the current in the coil has ceased.

102. We may say, then, that a current of electricity

will be induced in a coil of wire by a magnet so long as there is a **relative movement between the coil and the magnetic field**, or, in other words, when there is a change in the number of lines of force passing through the coil.

103. If we continue the experiment and **withdraw the magnet from the coil**, the needle of the galvanometer will again be deflected, but this time in the opposite direction, indicating that a current of electricity has been generated in the coil in the opposite direction to that produced by thrusting the magnet into the coil.

In effect, thrusting a magnet into a coil is equivalent to increasing the number of lines of force passing through the coil, and *vice versa*, withdrawing the magnet from the coil is equivalent to decreasing the number of lines passing through the coil.

104. We may say, then, that **the direction of the current induced in a coil by a relative movement between it and a magnetic field depends upon whether the movement tends to increase or to decrease the magnetic lines of force passing through the coil.**

105. By similar experiments it will be found that the quicker we thrust the magnet into the coil, the greater will be the current induced in the coil; also that a stronger magnet, that is to say, a magnet with a greater number of lines of force, will induce a greater current in the coil than a weak magnet, even though the two be thrust into, or withdrawn from, the coil at the same speed.

106. We may say, then, that **the current induced in a coil depends upon the rate of change in the number of magnetic lines of force passing through the coil.**

In the above explanations we have taken the point of view that currents were generated in the coil. It must be remembered, however, that this is not, strictly

speaking, accurate. It is really an electromotive force that is induced in the coil, and the current only flows as a result of this electromotive force when the circuit through the coil is completed.

The word current is used merely to avoid complications.

107. Another variation can be made in these experiments which greatly affects the amount of current

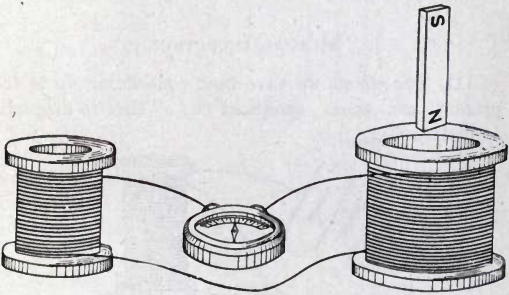


FIG. 19

induced in a coil, namely, the number of turns of wire of which the coil is composed.

108. If we wind two separate coils, one with say 100 turns of wire and the other with 200 turns of wire, we find that twice as much current is generated when we thrust a magnet into the larger coil as when we thrust the same magnet at the same speed into the smaller coil.

The best way to try this experiment is to connect both coils in series with the galvanometer, as shown in Fig. 19, and to introduce the magnet into one coil at a time.

By arranging it this way the resistance of the circuit remains the same, whichever coil is used.

109. We may say, then, that *the electromotive force induced in a coil is proportional to the* **rate of change of magnetic lines** *passing through the coil, and also to* **the number of turns of wire** *in that coil,* or, to put it as an equation:

110. Electromotive force = rate of change of lines × number of turns.

Mutual Induction

111. The effects we have been considering up to the present are those produced by "Electro-magnetic Induction."

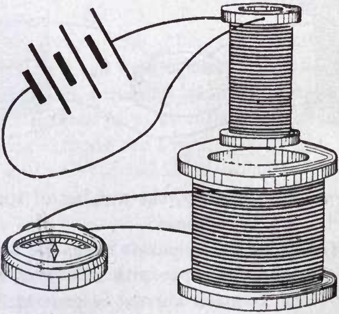


Fig. 20.

Referring to paragraph 89, we showed how a coil of wire through which an electric current was passing produced a magnetic field similar to that produced by a permanent magnet.

112. It is obvious, then, that in the experiments described in the last paragraphs we can produce exactly the same results by replacing the magnet by a coil of wire through which a current is kept flowing.

113. The effects then produced are known as those of **Mutual Induction**, and an illustration of this is shown in Fig. 20.

114. In the case of Mutual Induction, though, it is not necessary to move the first coil in and out of the second coil, for we can produce exactly the same effect, namely, that of changing the number of lines of force passing through the second coil, **by leaving the first coil permanently inside the second coil. and making and breaking the battery circuit through the first coil** by means of a switch, as shown in Fig 21

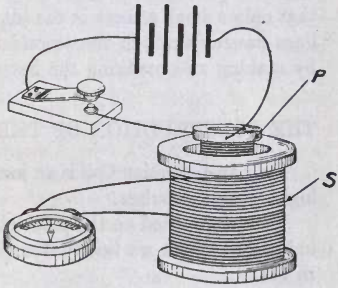


Fig 21

115 In these cases the coil P through which the current is flowing is called the **Primary Coil**, and the coil S, in which the current is induced. is called the **Secondary Coil**.

116 By referring to paragraph 97, it is obvious that the voltage induced in the secondary coil will be greatly increased in the above experiments if a core of iron is placed through the primary coil P.

117. If an iron core is used, the iron should be soft, for the following reason.

Soft iron will retain only a very small amount of the magnetism induced in it after the current passing round it has been interrupted. Hard iron, or steel, on the other hand, retains a very large portion of its magnetism after the current passing round it has ceased to flow.

The result, therefore, of using a steel core would be that only a small change in the total number of magnetic lines passing through the secondary would be obtained by making and breaking the battery circuit.

THE CONSTRUCTION OF THE INDUCTION COIL

118. An Induction Coil is an instrument for producing high-voltage impulses.

It is constructed on the principles of electro-magnetic induction, which we briefly described in paragraphs 98 to 117.

119. In paragraph 114 we showed how a current of electricity could be produced in a secondary coil by making and breaking the battery circuit through a primary coil.

In paragraph 109 we showed how the voltage, or pressure, of the electricity induced in the secondary coil depends upon two things:

(1) The rate of change in the number of magnetic lines of force which pass through the secondary coil.

(2) The number of turns of wire with which the secondary coil is wound.

120. The quicker the rate of change in the number of magnetic lines of force the greater the resultant

voltage across the secondary coil. Also, the greater the number of turns in the secondary coil the greater the resultant voltage across it.

121. By placing a core of soft iron in the primary coil we very greatly increase the total number of magnetic lines of force induced by the primary current (*vide* paragraph 117), and therefore, when the primary circuit is broken, we get a greater change in the number of magnetic lines of force passing through the secondary coil, and assuming that the time taken for the magnetism to die down is the same as before, we get a greater rate of change of magnetic lines passing through the secondary, and therefore a higher voltage is induced across it.

122. Further, by using a very fine wire we can wind a very large number of turns on to the secondary coil, thereby still further increasing the voltage induced across the secondary.

123. By designing a coil on these principles, it is possible to obtain voltages of 30,000 volts or more, using only a small accumulator battery giving 4 or 6 volts in the primary circuit.

124. We may now describe how an induction coil is actually made, and the means by which it can give automatically a continuous stream of high-voltage impulses, or sparks, when a low-voltage battery is applied to its primary terminals.

The mechanical construction is shown in section in Fig. 22, and the electrical connections are shown diagrammatically in Fig. 23.

125. The secondary coil A is wound with about 5000 turns of fine wire on an ebonite bobbin B, the bobbin having a hole through the middle sufficiently large to

take the primary coil with its iron core, the two ends of the secondary coil are brought one to each of the terminals E, E, which are called the "high-tension" terminals of the induction coil.

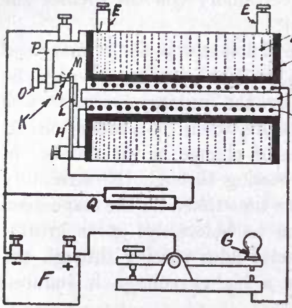


Fig. 22.

126. The iron core C is made of a bundle of soft iron wire, bound together with cotton tape, and round this core is wound the primary winding D, consisting of about 50 turns of fairly thick wire, through which the current from the primary battery has to pass in order to magnetise the iron core.

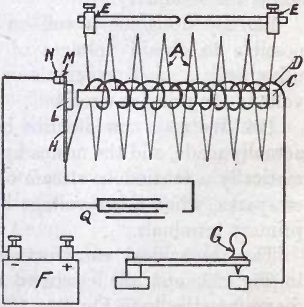


Fig. 23.

127. One end of this coil is taken straight to the positive terminal of the battery F, through the manipulating key G. The other end of the coil, however, instead of being connected straight to the negative terminal of the battery F, is connected to the spring arm or trembler blade H of the contact breaker K.

128. This trembler blade carries on its side, which is nearer to the core C, a small piece of soft iron L, and on its other side a platinum contact M. Another platinum contact N is carried on an adjusting screw O by a brass bracket P, in such a way that it comes immediately opposite the contact M, the spring of the trembler blade being adjusted so that normally the two contacts M and N are making contact. The brass bracket is connected to the negative side of the battery F.

129. The action of the coil can best be followed by referring to the diagram of connections in Fig. 23. The contacts M and N being in contact, if the arm of the manipulating key G is depressed, the electrical circuit through the primary coil is completed and a current will flow from the positive side of the battery F, through the manipulating key G, through the coil D, through the trembler blade H, through the contacts M and N, through the bracket P (Fig. 22), and back to the battery F.

130. The effect of the current passing through the coil D is to magnetise the iron core C, and the first effect of this magnetisation is to induce a voltage across the secondary coil of wire. This high voltage, however, is only a momentary impulse, for it depends, as already stated, upon the rate of change in the number of magnetic lines of force passing through the secondary coil, so that as soon as the iron core is fully magnetised by the primary current, the change in the number of magnetic lines ceases, and therefore the voltage across the secondary falls to zero.

131. If, however, the primary current flowing round the iron is interrupted, the iron core becomes demagnetised, and there is again a rapid change in the number of magnetic lines of force passing through the secondary

coil, and we get a second high-voltage impulse across the secondary coil.

132. Now this interruption of the primary circuit is effected automatically by the contact breaker, for as soon as the iron core becomes magnetised it attracts the piece of iron L (Fig. 23), which, as already explained, is fixed to the trembler blade, carrying the contact M, thus separating the contact M from the contact N, and interrupting the primary circuit.

133. As soon as the circuit is thus broken the iron core C ceases to be a magnet, and therefore ceases to attract the piece of iron L, allows it to fly back to its original position, and the primary circuit is again completed through the contacts M and N coming together again.

The same cycle of events repeats itself in rapid succession so long as the manipulating key G is kept depressed.

134. The resulting effect in the secondary coil is therefore a corresponding number of high-voltage impulses across the coil, **one impulse being induced when the magnetism in the iron grows** owing to the primary current passing around it, and a **second impulse being induced in the opposite direction when the magnetism of the iron collapses** owing to the primary current ceasing to pass around it.

135. As a matter of fact, the magnetism in the iron grows comparatively slowly owing to the inductance of the winding (*vide* paragraphs 61 and 66) as compared with the rate at which the magnetism collapses on breaking the circuit, and as the voltage across the secondary coil is proportional to the rate of change of magnetic lines of force, we get a very much bigger

voltage during the collapse of the magnetism than during the growth of the magnetism; that is to say, we get a higher voltage when the primary circuit is interrupted than when it is completed.

136. Fig. 24 shows diagrammatically the voltage induced across the secondary of an induction coil. The upper part of the curve shows the voltage impulses due

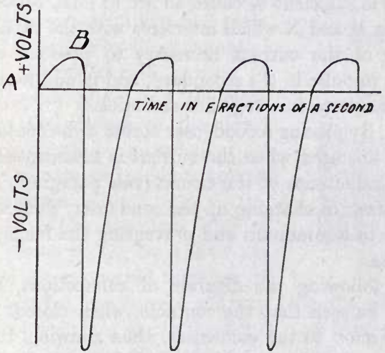


FIG. 24.

to the making of the primary circuit, and the lower part of the curve shows the voltage impulses due to the breaking of the primary circuit.

137. From A to B the magnetism in the iron core is growing comparatively slowly, and the voltage induced across the secondary only rises to about 1000 volts.

At the point B the primary circuit is broken, and a very high voltage, perhaps about 20,000 volts, is induced across the secondary in the opposite direction, owing to the very rapid collapse of the magnetism in the iron.

138. Another important part of the induction coil is the condenser, which is connected across the contact breaker K, shown at Q in Figs. 22 and 23.

Owing to the inductance of the primary winding when the current is suddenly interrupted at the contacts M and N, a high voltage is generated in the primary coil in the opposite direction to the applied voltage. This voltage is sufficient to cause an arc to form between the contacts M and N which interferes with the rapid interruption of the current necessary to produce a high-voltage impulse in the secondary, and in addition causes the contacts to fuse together and stick.

139. By placing a condenser across these contacts the energy liberated when the current is interrupted owing to the inductance of the circuit (*vide* paragraph 62) expends itself in charging up the condenser, thus reducing the arc to a minimum and preventing the fusing of the contacts.

By following the diagram of connections, Fig. 23, it will be seen that the contacts, when closed, form a short-circuit to the condenser, thus allowing the condenser to discharge itself through these contacts when they fly together again, if it has not already discharged itself through the primary winding of the induction coil.

Production of Electricity by Chemical Action

140. **A Cell** is an apparatus for producing a current of electricity by chemical action.

141. **A Battery** consists of a number of cells joined together either in parallel or series.

142. A cell usually consists of two dissimilar metals, such as copper and zinc, immersed in a solution of acid or salt, as shown in Fig. 25.

Chemical action is set up by the acid attacking the zinc, and the energy liberated by the dissolving of the zinc appears in the form of electric potential on the **submerged surface** of the zinc plate.

There is, however, practically no chemical action set up on the copper plate, and therefore no electric potential is produced on the surface of the copper plate, with the result that the submerged portion of the zinc plate is at a higher electric potential than the submerged portion of the copper plate, and therefore **below the surface of the liquid** the zinc can be regarded as of positive potential, and the copper as negative.

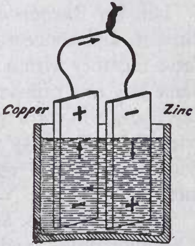


Fig. 25.

143. When the two ends of the plates which are above the liquid are connected together by a conductor, the current will flow from the zinc plate to the copper plate under the liquid, and from the copper plate to the zinc plate above the liquid.

144. For this reason the terminal which is joined to **the copper plate is called the positive terminal of the cell,** and the terminal which is joined to **the zinc plate is called the negative terminal of the cell.**

145. Cells of this nature are called Primary Cells, and a battery consisting of two or more of such cells properly joined together is called a " Primary Battery."

Accumulators

146. **An Accumulator** is a cell in which the two plates are made of such materials that when a current of

electricity is passed through them from some outside source in a certain direction, chemical actions are set up between the plates and the electrolyte surrounding them, thus altering the chemical composition of the materials of which the plates were made.

147. This is known as " **charging** " the accumulator, and the current which is passed through the accumulator is known as the **charging current.**

148. On disconnecting the source of the charging current, and connecting the two plates of the accumulator together with a conductor, the cell will act in the same way as a primary cell, the chemical composition of the plates will start to return to its original state, and a current of electricity will pass from the cell through the conductor in the **opposite direction to the charging current.**

149. Such cells are called " **Secondary cells** " or " **accumulators,**" and a battery, consisting of two or more of such cells properly joined together, is called an " **Accumulator Battery,**" " **Secondary Battery,**" or " **Storage Battery.**"

Diagrams of Connections

150. For convenience in illustrating graphically the connections of an electrical circuit, certain symbols are used to denote the particular predominant property which that part of the circuit possesses. When several of these symbols are used to illustrate certain connections, it is known as a " **Diagram of Connections.**"

At the beginning of this book we give a number of these symbols, and certain variations of them which are most commonly met with.

THE PRINCIPLES OF WAVE MOTION

151. Before showing how the principles of electricity and magnetism are applied to wireless telegraphy, we must first explain the principles of wave motion on which the science of wireless telegraphy is founded.

152 Let us make a simple experiment to illustrate these principles.

In a pool of water, and at opposite sides of it, two pieces of wood are floating. If we strike one of these pieces of wood with a hammer, or in any other way cause it to disturb the water, it will be observed that a number of ripples or waves are sent out in all directions. Follow these waves until they reach the piece of wood at the far side of the pool and it will be observed that this second piece of wood is set in motion by the waves.

153. This is analogous to what occurs between two wireless stations. The piece of wood that is struck with a hammer corresponds to the transmitting station, the water to the transmitting medium, and the piece of wood at the far end of the pool to the receiving station.

154 *The substance through which, or on the surface of which, a wave travels* is called **the medium.**

Properties of Waves

155. **A wave has the property of propagating itself radially from a given point.** That is to say, once a wave has been started it travels in all directions away from the point at which it was started.

An illustration of this can be seen by dropping a stone into the middle of a pool of water. The displacement of the water by the stone starts a circle of ripples or waves, which circle gets bigger and bigger until either the waves die out or they reach the edge of the pool.

156. A wave has also the property of producing at any point in its path a disturbance in a body suspended in the medium similar to the disturbance which started the wave.

Thus if we start a wave of water on the surface of a pond by moving a stick in it, the wave will cause a motion in another stick floating on the surface of the pond at any point in the path of the wave.

Communication by Wave-motion

157. We may say, then, that if we have a means of starting waves at one point in a medium, and a means of detecting the passage of the waves at another point in the same medium, we have a means of communicating signals between these two points.

In order to communicate intelligence, however, we must be able to distinguish between different signals, and by means of the Morse Code (which is given in full at the beginning of this book) the number of different signals which it is necessary to produce at a receiving station to communicate intelligence in the form of words has been reduced to two, namely, the dot and the dash, or "short and long." By different combinations of the dot and dash we can represent every letter in the alphabet, thus enabling us to spell out letter for letter any word or sentence desired.

158. As an illustration, let us see how the Morse Code could, for example, be applied to the method of communication described in paragraph 153.

If we were to fix above the receiving piece of wood a sheet of iron, or some other object, so that every time a wave passed under it the piece of wood knocked against this object, we should get a sound produced in the form of a tap.

A single blow from the hammer on the transmitting piece of wood might produce two or three ripples, which would be translated by the receiving piece of wood into two or three taps. Several blows in rapid succession on the transmitting piece of wood would send out perhaps a dozen ripples following one another. These would be translated by the receiving piece of wood by a similar number of taps, thus giving us a ready means of producing a short or long effect at the receiving end, and enabling us to use the Morse Code for communicating intelligence.

159. An important point to understand is that although a wave travels from one part of a medium to another, **the medium itself does not travel**, and, except for an up-and-down or to-and-fro motion while a wave is passing, remains where it is. This can readily be illustrated by placing something in a pond, such as a fishing-float, which lies in the water with its top just above the surface, and starting a wave some little distance from the float. When the wave passes the float, the latter will be seen to move up and down, but will not be carried along with the wave.

Measurements of Waves

160. In order to explain how the properties of waves, more especially of electric waves, can be utilised for the purpose of communication, we must know something about the different qualities or measurements of waves and the terms used to describe them.

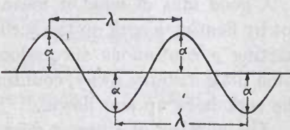


Fig. 26.

161. **The amplitude** of a wave is the distance from the highest point to the normal level, and is usually denoted by the Greek letter a (*alpha*), as illustrated in Fig. 26.

162. **The length** of a wave is the distance from the crest of one wave to the crest of the next, and is usually denoted by the Greek letter λ (*lambda*), as illustrated in Fig. 26.

If we notice the surface of a pond over which a wave is travelling, we see that only part of the wave is above the normal level of the water, for there is a corresponding depression between the crests. A complete wave consists of the half which is above and the half which is below the normal level.

163. **The velocity** of a wave or the **speed of radiation** is the distance a wave will travel radially in one second.

Thus, if we start a wave on the surface of a pond, and it takes one second from the time it was started for the circle of ripples to reach a point on the pond 10 feet away from the starting-point, the velocity of the wave is 10 feet per second.

164. **The frequency** of a wave is the number of complete waves that will pass a given point in one second, or, in other words, the rapidity with which one wave follows another.

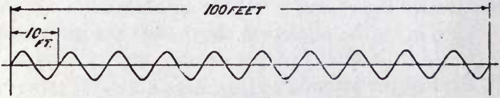
A good idea of what is meant by frequency can be got by floating a cork on the surface of a pond, and after starting a continuous succession of waves, or ripples, some little distance away, counting the number of times the cork bobs up and down.

The number of times it does this in a second is the frequency of the wave.

165. **Another definition of frequency can be made in terms of the wave-length and the velocity.** The explana-

tion can be more readily followed by referring to Fig. 27. Imagine a continuous succession of waves following each other, as shown in Fig. 27; if we take two points A and B to represent the distance that any one of these waves will travel in one second, the total number of waves included between the points A and B will be the frequency of the wave, **because all of these waves have to pass the point A in one second.**

166. Now the number of waves included between the points A and B is equal to the distance from A to B divided by the length of the wave.



A Fig. 27. B

Take an example: Suppose the waves are travelling at the rate of 100 feet per second, then the distance from A to B is 100 feet; and suppose there are ten waves included between the points A and B, as shown in the diagram, it follows that the length of each wave is 10 feet.

167. We may say, then, that

$$\text{Frequency} = \frac{\text{Velocity}}{\text{Wave-length}},$$

and therefore by transposing,

$$\text{Velocity} = \text{Frequency} \times \text{Wave-length}$$

or

$$\text{Wave-length} = \frac{\text{Velocity}}{\text{Frequency}}.$$

PRESSURE WAVES

168. The waves we have been considering travel along the surface of water, but another kind of wave can be formed which travels through the body of a substance. **Such waves are called " Pressure Waves " and obey the following laws.**

169. (1) **A pressure wave travels at a definite speed depending on the substance or medium,** and the speed in a given medium remains the same no matter how big or how small the waves may be.

Generally speaking, the speed or velocity is greater the greater the elasticity [1] of the substance.

Thus in air the velocity is about 1090 feet per second, in water it is 4700 feet per second, and in steel it is 16,400 feet per second.

170. (2) **The amplitude of the wave very rapidly gets smaller as the wave gets farther from its starting-point,** until, if given sufficient room, it finally dies out altogether; in other words, the amplitude decreases as the distance from the starting-point increases.

171. (3) **The length of the wave remains the same no matter how far it is from its starting-point**; in other words, the wave-length, once started, remains constant, and is quite independent of the amplitude.

AETHER WAVES

172. In order to explain the phenomena of light, radiant heat, and electric waves, physicists have imagined a substance or medium called the " **aether,**" and waves similar to the pressure waves we have just been con-

[1] The elasticity of a substance is the force which must be applied to a given length of unit cross-section in order to double this length It must not be confused with the term "flexibility" used in par. 30.

sidering produce rays having different properties, according to the wave-length.

173. The shortest wave-lengths known produce X-rays, which have the property of passing through many bodies that are impervious to light rays, and of causing chemical action on photographic plates. The next in length produce actinic rays, causing chemical action similar to those produced by X-rays. Then light rays, which act on the eyes, producing the effect of vision; and heat rays which produce the effect of warmth; and, finally, "electric" rays, which will produce electric currents in conductors, and which are used in Wireless Telegraphy.

The following is a table of some of these wave-lengths

X-rays, about 2·5 millionths of an inch.[1]

Actinic rays of maximum intensity, 10 millionths of an inch.

Light rays, from 10 to 18 millionths of an inch.

Heat rays of maximum intensity, about 15 millionths of an inch.

Electric rays, shortest measured, 0·24 inch; used in wireless telegraphy, 300 feet to 50,000 feet.

174. All these waves obey the laws stated for pressure waves (paragraphs 169 to 171), and have the properties explained in paragraphs 155 and 156, and, since they all travel through the same medium, the velocity of all of them is that of Light—namely, 300,000,000 metres, or about 1,000,000,000 feet per second, equal to 186,000 miles per second.

175. The velocity of aether waves is thus seen to be

[1] The one-thousandth part of the thickness of a cigarette paper is about one-millionth of an inch.

far greater than that of air waves. It is for this reason that, as light travels in the form of aether waves, and sound travels in the form of air waves, if we watch a battleship from a distance firing guns, we see the flash of the gun long before we hear the report.

176. Caution must be exercised when the effects produced by surface waves are used to explain the phenomena of Wireless Telegraphy, Sound, or other effects transmitted by pressure-wave radiation, because **surface waves do not follow altogether the laws governing pressure waves.** Thus they do not follow Law No. 1, for the velocity of the surface waves on water depends on the wave-length and amplitude, *i.e.* big waves travel faster than small ones; further, they do not follow Law No. 2, for the amplitude of surface waves is not independent of the wave-length, thus if a surface wave of definite length be started, it will be found that its length will increase as its amplitude decreases.

In general we may make the following deductions regarding the effects produced by wave motion.

177. (1) **The nature of the effect produced by a wave,** or a series of waves in a given medium, on the senses, or on other matter, depends upon the frequency of the waves.

Thus, if the frequency of waves travelling in aether lies between about 1200 billions and 660 billions, they will produce an effect on the eyes known as **light**, and the various frequencies between those limits will produce **various colours.**

178. (2) **The strength of the effect produced by a wave** depends upon the amplitude of the wave, and since the amplitude of the wave gets smaller as the wave gets farther from its starting-point, *the effect produced by a*

wave will be weaker as the distance from its starting-point is increased.

Thus, taking a lighted candle as the starting-point of a number of light waves, it will be observed that the strength of the light it produces on, say, a sheet of paper is very rapidly reduced as the distance between the paper and the candle is increased.

Communication by means of Aether Waves

179. In paragraph 152 we showed how, by means of waves on the surface of a pond, we could communicate signals from one point to another, but the method there described would be exceedingly slow, and would, for many other reasons, be quite impracticable.

Since Aether Waves also possess the properties mentioned in paragraphs 155 and 156, it is obvious that these waves can be used in a similar manner for the purpose of communicating signals from one point to another (*vide* paragraph 157), with the great advantage that, the speed of radiation being 186,000 miles per second, communication from one point to another will be practically instantaneous.

180. Communication has, for many years before "Wireless Telegraphy" was thought of, been carried out by means of Aether Waves in the form of light waves, by using searchlights, heliographs, and similar apparatus, but this method has the disadvantage that the range is small and intervening objects interrupt communication.

The discovery leading to Marconi's great invention of Wireless Telegraphy was made by Hertz. Hertz first experimentally proved the existence of electric waves and indicated how they could be produced by

electrical means. For this reason they are sometimes known as Hertzian waves.

It should be understood, though, that Hertz only demonstrated the existence of these waves, and did not in any way attempt to utilise them as a means of communication.

181. **The advantages which electric waves have over light waves for communication can be briefly stated as follows:**

182. (1) **They will pass through, or over, intervening objects** which are impervious to light waves, and therefore these objects will not interrupt communication.

183. (2) **They will follow the curvature of the earth,** and therefore the range of communication can be increased beyond the limits of the horizon, whereas in the case of light waves it is necessary that the point from which a ray of light is being received is above the horizon.

PRODUCTION OF WAVES

184. We have already stated that waves formed on the surface of a body do not follow exactly the same laws as pressure waves, but the analogy of the wave produced on the surface of a pool is useful in explaining how a pressure wave is produced.

Let us first understand clearly what the difference is between a wave produced on the surface of a body and a wave produced through the substance of a body.

185. The wave on the surface of a pool depends for its existence upon a **difference in the height** of adjacent particles of water above or below the normal level of the water. It may therefore be called a **height wave.**

186. The wave produced through the substance of a

body, on the other hand, depends for its existence upon **a difference in the pressure** of adjacent particles of the substance through which it is travelling above or below the normal pressure of that substance. It is therefore called a **pressure wave.**

Production of Height Waves

187. It is not generally known why a height wave is produced on the surface of a pool when a stone is dropped into it, and therefore an explanation of it will be useful before describing how a pressure wave can be started.

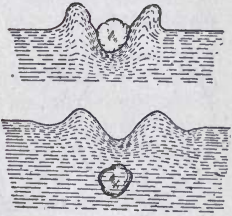


Fig. 28.

188. It is evident that as we fill up a pond we raise the height of the surface of the water in that pond. It does not matter with what material we fill the pond up, whether it be water or stones or any other matter, the effect is the same, namely, the height of the surface of the water is increased.

189. It follows, then, that if we drop only a single stone into a pool, we increase the height of the surface of that pool, even though it be ever so slightly.

Owing to the inertia of the water, however, the height of the water is not immediately increased over the whole surface of the pool, for the inertia of the water tends to prevent it from rising. The result is, that when the stone is plunged into a pool, the water that is displaced by the stone forms in a heap all round the stone, as shown in Fig. 28. A height wave is thus started on the surface of the water, and travels radially like an ever-

expanding circle with the point where the stone entered the water as its centre.

190. The size of the pool makes no difference to the production of the wave, for it is just as easy to start a wave in the middle of the ocean as it is in a pool of water, for the effect does not depend upon the inertia of the whole mass of water, the inertia of the water immediately surrounding the stone being sufficient.

Production of Pressure Waves

191. We may take a very similar experiment to explain the production of a pressure wave in the air, but it must be remembered in this experiment that instead of starting a circle of maximum height on the surface of a body we start a circle, or rather a sphere of maximum pressure, in the substance of the body.

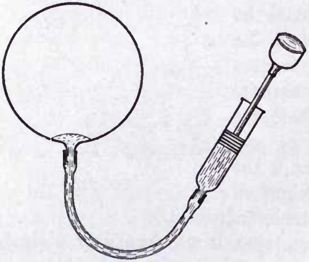


Fig. 29.

Let us imagine a closed chamber full of air with an opening at the bottom through which we can pump some water, as shown in Fig. 29.

192. It is well known that if we pump anything into the chamber we increase the pressure on the air inside it. It does not matter what we pump in, whether it be water or air, the effect is the same, namely, the pressure is increased.

193. We will suppose, for the purpose of explanation,

that the chamber is full of air at normal pressure and that we increase the pressure of this air by pumping water into the chamber.

194. If, then, we suddenly force water into the chamber, owing to the inertia of the air we momentarily only increase the pressure in the air immediately above the surface of the water, or in other words, the air that is displaced by the water forms a pressure heap which travels forward in the form of a pressure wave through the substance of the air

195. It must be understood, though, that **the air itself does not travel**, but only the pressure of the air travels, just as tho water that is displaced by the stone does not travel, but only the height of the water travels.

196 It must be further understood that the formation of a pressure heap of air in the chamber does not depend on the inertia of the whole of the air in that chamber, the inertia of the air immediately above the water being sufficient, and therefore just as the height wave can be produced as easily in the middle of the ocean as in the middle of a pond, so can a pressure wave of air be produced in the open atmosphere just as easily as it can be in a closed vessel, it being only necessary to displace some of the air at a given point to start a wave.

197. Since the air is invisible it is impossible to see these pressure waves, and they can only be imagined; but a simple experiment can be made in which a pressure wave can be actually seen, and which compares very closely to the experiment explained above.

198. Let us make up a very long spiral spring out of fine steel wire, as shown at A in Fig. 30, and support it at intervals along its whole length by threads, so as to allow it a greater freedom of motion than if we laid it on

a table where any motion would have to overcome the friction of the table.

199. If now we strike one end of this spiral a sharp tap with a hammer, it will be observed that, at the moment of impact, only that part of the spring immediately in front of the hammer will be compressed, while the rest of the spring remains as it was.

200. This compression will be seen to travel along the whole length of the spiral, like a pressure wave, leaving that part of the spiral between it and the hammer in its normal state after it has passed; thus at the moment of

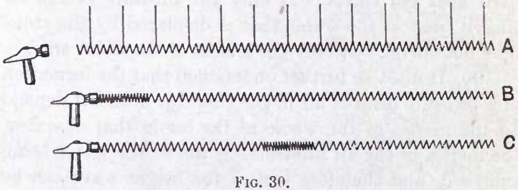


FIG. 30.

impact the spring will take the form as shown at B in Fig. 30, and when the wave has travelled half the length of the spiral, the spring will take the form as shown at C in Fig. 30.

201. To carry out this experiment successfully, the inertia of the spring must be made big by using a very long spiral, say 30 feet long; also the wire forming the spiral must be extremely fine, so as to allow it to compress easily without exerting too great a force against the inertia of the whole spring, otherwise the effect will be produced too rapidly for observation, and it will appear that the spiral is only moved bodily by the hammer. A suitable spiral would be a coil of fine steel

wire, say No. 28 gauge, wound on a coil say 1 inch in diameter and 20 feet or 30 feet long.

The spring should be suspended by threads as long as possible and at intervals as frequent as possible.

202. In the above experiments we have considered that a wave is produced by a sudden increase in the pressure at a given point. This, however, is not strictly accurate, for **a single pressure pulse does not produce a complete wave**, but only one-quarter of a wave.

203. *To produce a complete wave, it is necessary that the pressure be first increased above normal, then reduced to normal, then reduced to below normal, and finally increased again to normal.*

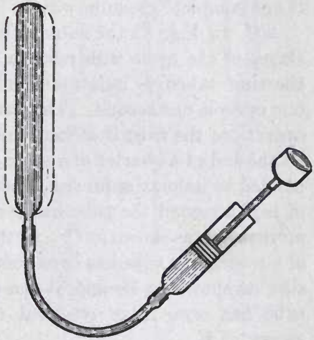


Fig. 31.

204. An illustration of this is given in Fig. 31, where a long india-rubber tube is shown full of water. The size of the tube can be increased or decreased by connecting it through a pipe to a pump, capable of pumping more water into the tube and of sucking some of the water out of it, thus increasing and decreasing the size of the tube.

The full line in the illustration shows the normal size of the tube, and the two dotted lines show the maximum and minimum sizes of the tube.

205. When the tube has been expanded, reduced to

normal size, contracted and increased to normal size, it is said to have passed through **one complete cycle** of operations.

206. As the size of the tube is increased, the pressure of the air surrounding it is increased above normal, and *vice versa* as the size of the tube is decreased the pressure of the air surrounding it is decreased below normal.

Therefore, if we pass this tube through one cycle of conditions, we shall produce in the air surrounding it one complete pressure wave.

207. In Fig. 32 the same tube is shown in different stages of the cycle **with relation to time**, assuming that the time taken to inflate and deflate the tube through one cycle is one second. Thus at the commencement of operations the tube is at its normal size, as shown at A. At the end of a quarter of a second the tube has been expanded to its maximum size, as shown at B. At the end of half a second the tube has been reduced again to its normal size, as shown at C. At the end of three-quarters of a second the tube has been contracted to its minimum size, as shown at D, and at the end of one second the tube has once more returned to its normal size, as shown at E.

208. The effect on the pressure of the air surrounding the tube, with relation to the time, can be illustrated diagrammatically by the curve drawn below the illustration of the tube, where the distance of the curve above or below the horizontal line represents the increase or decrease in the pressure of the air, or what comes to the same thing, the increase or decrease in the size of the tube and the distance along the horizontal line represents the progress of time

It is evident that the frequency of the wave produced depends entirely upon the frequency of the impulses producing it.

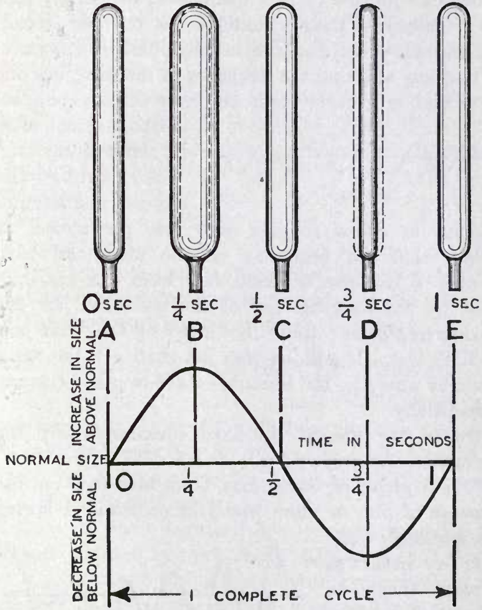


FIG. 32.

209. In paragraph 167 we defined the relation between the length of the wave, the frequency, and the speed at which it was radiated. This relation will be better

understood by applying it to the foregoing illustration of the production of a complete wave.

210. Since it took one second for the tube to pass through a complete cycle of operations, we can say that **the frequency of these operations** was one per second, and since the cycle of operations only produced one wave, we may say also that **the frequency of the wave** was one per second, or in other words, the wave was not complete until one second after its commencement.

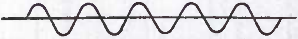


Fig. 33.

211. Since the speed of radiation of pressure in air is roughly 1000 feet per second, it follows that the beginning of the wave will have reached a distance of 1000 feet from the starting-point by the time the end of the wave has just left the starting-point; thus the length of the wave will be 1000 feet. It will be seen we shall get the same result by applying the formula—wave-length = velocity ÷ frequency.

Up to the present we have considered only the production of a single wave.

212. A group of waves may be defined as a natural sequence of two or more waves immediately following one another without any interval between them, as illustrated in Fig. 33.

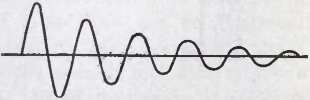


Fig. 34.

213. If a group of waves is produced in such a way that **each successive wave has the same amplitude**, as shown in Fig. 33, the waves are said to be "**continuous.**"

214. If a group of waves is produced in such a way that the **amplitude of each successive wave is less than its predecessor**, as shown in Fig. 34, the waves are said to be "**damped.**"

215. A group of waves is produced by a series of periodic displacements of the medium, which follow one another without an interval.

216. It is obvious from the experiments described in paragraphs 203 to 207 that if we repeat the cycle of operations of expanding and contracting the rubber tube periodically, we shall produce a group of waves, and if the extent of these expansions and contractions is maintained, the result will be to produce a group of continuous waves; but if the extent of these expansions and contractions gradually gets smaller and smaller till the tube finally comes to rest at its normal size, the result will be to produce a group of damped waves.

PRODUCTION OF ELECTRIC WAVES

217. In order to convey signals from one point to another by means of wireless telegraphy it is necessary to have an apparatus for producing electric waves at one point, and an apparatus for detecting the presence of such waves at the other point.

218. We have described how pressure waves in the air are produced by the periodic displacement of the air at a given point through a definite cycle, causing the pressure in the air to vary from normal pressure to a positive pressure, to normal pressure, to a negative pressure, and finally to normal pressure.

219. Electric waves in the aether are produced by the periodic displacement of the aether at a given point through a similar cycle.

220. These displacements of the aether are produced by electrical charges in what is known as the **Aerial Wire.**

For the purpose of explanation we may regard the aether as a substance which exists in everything.

221. When we charge up a condenser, **we put the dielectric of the condenser in a state of strain.** This state of strain in the dielectric exerts a pressure on the aether which exists in the dielectric, and the pressure pulse thus produced will radiate through the aether in a similar way to the radiation of the pressure pulse in the air which we described previously.

222. **This, however, only produces one pulse**, and to produce a complete wave in the aether we must pass the condenser through a complete cycle of operations by first charging it positively, then discharging it, then charging it negatively, and again discharging it (*vide* paragraph 203).

223. To produce a group of waves we must pass the condenser through a series of these cycles following each other in periodic sequence.

224. If during each cycle the condenser is charged to the same extent, *i.e.* to the same voltage, the group of waves produced will be " continuous," but if each successive charge of the condenser is weaker than the last, the group of waves produced in the aether will be " damped."

In this book we shall only describe the production of damped waves.

225. Suppose we suspend a length of wire in the air from a mast and insulate it from the earth, as shown in Fig. 35, **we may regard the wire, the air, and the earth as forming a condenser,** in which the wire acts as one plate of the condenser, the air as the dielectric, and the earth as the other plate.

226. And suppose we have a way of charging and discharging it in rapid succession by means of a suitable electrical generator G, first charging it positively and then negatively, each charge and discharge produces a pressure pulse in the aether, and **the four pulses**—positive charge, discharge, negative charge, discharge—**form a complete electric wave**, which starts travelling into space with the velocity of light, namely 300,000,000 metres per second.

227. Such a wire is known as the **Aerial Wire**, and is given various shapes, as we shall describe later.

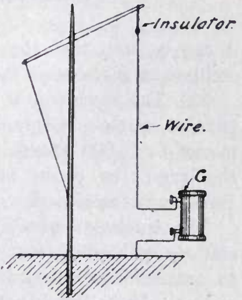


FIG. 35.

228. The analogy of the expansion and contraction of the india-rubber tube, described in paragraph 204, can be used to explain the action of charging and discharging the aerial wire.

229. Whilst being charged, a current of electricity will flow into the wire, just as a current of water was made to flow into the tube to expand it. The current will be large at first and diminish as the aerial becomes charged, until it ceases to flow when the aerial is fully charged. The instant it has ceased to flow the current will start to flow in the opposite direction, as the aerial discharges; and so on, the current will flow backwards and forwards, charging and discharging the aerial through successive cycles.

230. Such a current of electricity is called an **oscillating current.**

231. It is obvious that the frequency of the wave produced in the aether will depend entirely upon the frequency of the oscillations in the aerial (*vide* paragraph 208).

232. It follows, therefore, that by varying the frequency of the oscillations in the aerial we can vary the length of the wave radiated.

From the formula

$$\text{Wave-length} = \frac{\text{Velocity}}{\text{Frequency}}$$

it can be seen that the greater the frequency of the oscillations the shorter the wave-length.

233. The wave-lengths usually employed for the purpose of wireless telegraphy vary in length from 100 metres to 15,000 metres or more. Generally speaking, the larger the power of the station the longer the wave-length employed.

The wireless apparatus on ships and at the shore stations with which the ships communicate is designed to transmit wave-lengths of 300 metres and of 600 metres. Long-distance stations use wave-lengths varying from 1000 to 15,000 metres.

234. From the formula quoted above it will be found that the number of oscillations per second required to produce a wave-length of 15,000 metres is 20,000, and the number per second required to produce a wave-length of 100 metres 3,000,000.

235. Such oscillations are known as **High-frequency** or **oscillatory currents**, to distinguish them from the Low-frequency or alternating currents of between 25 and 1000 per second produced by ordinary alternating current dynamos.

PRODUCTION OF HIGH-FREQUENCY OSCILLATIONS

236. There are several ways of producing high-frequency oscillatory currents. For the present we will confine ourselves to the method known as the "spark" method.

237. If a condenser is charged and then suddenly discharged by connecting its two opposite plates together with a conductor, not only does the current flow from the positively charged plate to the negatively charged plate until the plates are at the same potential, **but the current continues to flow in the same direction on account of the inductance** (*vide* paragraph 61) of the conductor, causing that side of the condenser which before was negatively charged to become positively charged, and *vice versa*.

238. The reversed charge, however, does not charge the condenser to the same extent, *i.e.* to the same voltage as the original charge, because a certain amount of the energy is frittered away by the resistance of the circuit, and a further amount of energy is used up in the production of pressure waves.

239. The action is then reversed with the same effect, and so on, each time with less energy, until the whole of the energy originally in the condenser is absorbed. An oscillating current of gradually diminishing strength is therefore produced.

240. The action can be illustrated by making the experiment with the pendulum illustrated in Fig 36, where the weight W is shown suspended from a fixed point A by a piece of string B.

241. If this weight be displaced to the position showr

by the dotted line marked W_1 and then released, it will not immediately take up the position W, but owing to the momentum of the weight will swing backwards and forwards between the positions W_1 and W_2.

242. Owing to the friction between the weight and the air, and also to the fact that it gives up some of its energy to the surrounding air in forming pressure waves,

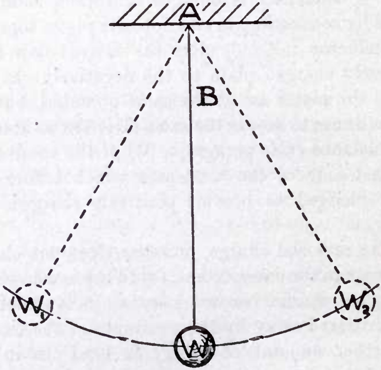


FIG. 36.

each swing will be a little shorter than the last, and it will finally come to rest at the position W, after making a number of swings.

243. In this case the number of swings which take place in a second—that is, the frequency of the oscillations—can only be varied by varying the length of the string.

244. A similar experiment can be made with a vibrator, shown in Fig. 37, in which there is a flat steel

spring B, fixed firmly at the point A, and carrying a weight W at its other or free end.

If the weight be displaced and released, it will swing or "oscillate" between the position W_1 and W_2.

245. In this case the number of swings per second will depend upon the flexibility of the spring B and also upon the inertia of the weight W, and we can therefore **vary the frequency** either by **varying the flexibility** of the spring or by **varying the weight.**

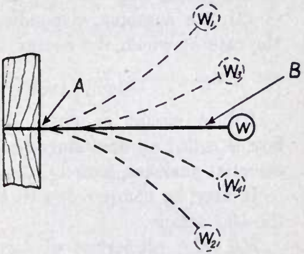


FIG. 37

246. It will be found that the longer or thinner and therefore the greater the flexibility of the spring, the less the number of swings per second, also the greater the weight W the less the number of swings per second.

247. The distance between the position W_1 and the position W is called the maximum amplitude of the swing, and generally half the distance between successive positions, such as W_3, W_4 in Fig. 37, is called the amplitude.

248. Owing to friction of the air and also to the energy radiated in the form of pressure waves, the amplitude will start at a maximum and gradually diminish until the spring comes to rest in its normal position. **The rate at which the swing decreases is called the "damping."**

249. The frequency will, however, remain constant quite independently of the amplitude; that is to say,

in Fig. 37 the time taken for the weight to travel from the position W_1 to W_2 and back again will be exactly the same as the time it takes to travel from the position W_3 to W_4 and back again.

250. To summarise, two matters have to be considered in connection with such a vibrator, viz.:

(1) **The frequency**, depending upon (1) the flexibility of the spring and upon (2) the mass of the weight.

(2) **The damping**, depending upon the friction and the rate at which the energy is radiated.

Oscillatory Circuits

251. A circuit in which an oscillating current will flow is called an **oscillatory circuit, and must possess two essential qualities, namely, Capacity and Inductance.**

It may be compared with the vibrator described in the last article.

252. The properties of the vibrator which decide the frequency of the vibrator are its mass and its springiness.

We have already explained in paragraphs 28 and 62 that the property of capacity is analogous to that of springiness and the property of inductance is analogous to that of mass.

Similarly, therefore, the properties of an oscillatory circuit which decide the frequency of the oscillating currents that will flow in it, and therefore the wave-length it will produce, are its Inductance and its Capacity,

253. Also the property which tends to stop or "damp" the vibrations of the vibrator is friction and radiation of energy. Similarly the property which tends to damp the oscillating current in an oscillatory circuit is the Resistance of the circuit and radiation of energy.

254. Obviously **resistance is an undesirable property**, as it absorbs energy. In every oscillatory circuit, therefore, the resistance is reduced to a minimum quantity, which is effected by increasing the size of the conductor and reducing its length as much as possible; there is, however, always a certain amount of resistance left.

255. As oscillatory circuits are used for the production of electric waves, it is important to know the relation between the wave-length and the capacity and inductance of the circuit.

256. It will be found that *as we increase either the value of the capacity or of the inductance of the circuit, so do we decrease the frequency of the circuit*, just as the frequency of a vibrator is decreased by increasing either its springiness or its mass.

257. The frequency of an oscillatory circuit is inversely proportional to the square root of the capacity and the square root of the inductance. And since the wave-length is inversely proportional to the frequency, it follows that the wave-length produced is proportional to the square root of the capacity and the inductance.

258. This law can be expressed as a formula, thus:

$$\text{Wave-length} = \sqrt{\text{Capacity}} \times \sqrt{\text{Inductance}},$$

or using the symbols by which these quantities are known,

$$\lambda = \sqrt{C \times L}.$$

259. This formula does not define what units are used to measure the different qualities. But if we measure the wave-length in metres, the capacity in microfarads, and the inductance in microhenries the formula becomes

$$\lambda(\text{m}) = 1885 \sqrt{C(\text{mf}) \times L(\text{mh})}.$$

Energy and Power in Oscillatory Circuits

260. In paragraph 178 we explained that the strength of the effect produced by a wave depends upon the amplitude of the wave, and since the amplitude of the wave decreases very rapidly as the distance it has travelled is increased, it follows that the effect produced on a receiver gets rapidly weaker as the distance from the transmitter is increased.

261. It is evident that to get a stronger effect at the same distance, or to produce the same effect at a greater distance, we must increase the amplitude of the wave at the starting-point.

262. It is simpler to consider wave-motion as a means of radiating energy ; also to consider the effect produced by the wave on what we may call a receiver, as the amount of energy received.

263. The amount of energy received at any point must necessarily be very small compared with the total amount of energy radiated, because in radiating energy we spread that energy out over a large space ; thus the farther the energy has been radiated the greater the space over which it is spread.

264. Take the case of a wave on the surface of a pond. At the starting-point the whole of the energy in the wave is concentrated in a very small space, and therefore a receiver in the shape of a piece of wood of comparatively small dimensions would receive the whole of the energy in that wave. If, however, we took that same receiver to a point 6 feet away from the starting-point, that is to say, 6 feet away from the transmitter, by the time the wave reached it, it would be spread over the circumference of a circle 12 feet in diameter, and therefore only

a very small part of the whole of the wave would affect the receiving piece of wood, or, in other words, it would only receive a small part of the energy in the wave.

265. It is evident that the farther we get from the starting-point the smaller the proportion of energy which a given object will receive, although the energy in the whole of the wave remains the same.

266. The energy radiated depends upon the energy put into the oscillatory circuit producing the waves, and it is therefore important to know on what factors the energy in the oscillatory circuit depends.

267. In the method of exciting an oscillatory circuit which we are now considering, namely, the spark method, **the amount of energy put into the circuit depends upon the capacity of the condenser in the circuit, and the voltage to which it is charged.**

268. The vibrator described in paragraph 244 can be energised by applying an initial pressure to the end of the spring, thus bending the spring.

269. Similarly an oscillatory circuit is energised by applying an initial pressure, or voltage, to the condenser, thus charging it with electricity.

270. The amount of energy put into the vibrator depends upon the flexibility of the spring, and the initial pressure that is applied to it. Thus the greater the flexibility of the spring the greater the energy put into it by applying a given pressure. Also the greater the pressure applied to it, the greater the energy put into a spring of given stiffness.

271. Similarly the amount of energy put into an oscillatory circuit depends upon the capacity of the condenser in the circuit, and the initial pressure, or voltage, to which it is charged.

272. A little consideration, however, will show us that the amount of energy is not directly proportional to the voltage to which the condenser is charged, but is proportional to the square of that voltage.

273. Taking again the analogous mechanical case of the spring, it is evident that if we apply a force of, say, 1 lb. to a certain spring by hanging a 1 lb. weight to it, the spring will be stretched to a certain definite extent, as described in paragraph 29.

274. Let us suppose, for the purpose of explanation, that the spring is stretched 1 foot when a force of 1 lb. is applied to it, and let us for the moment suppose that throughout the process of being stretched a force of 1 lb. is being exerted on the spring by the weight, then it follows from the definition of the mechanical unit of energy given in paragraph 73 that 1 foot-pound of energy has been expended on the spring.

275. Now the amount which a given spring will extend is directly proportional to the force applied to it, thus in this case, if instead of applying a force of 1 lb. to the same spring we apply a force of 2 lbs. to it, the spring in this case will be stretched 2 feet.

If for the moment we again suppose that throughout the process of being stretched 2 feet a force of 2 lbs. is being exerted on the spring, then it follows that in this case 4 foot-pounds of work have been expended on the spring, because a force of 2 lbs. has been exerted in moving a body 2 feet.

276. In other words, although we have only applied twice the force to the spring, we have done four times as much work on it. Now provided there are no losses in overcoming the friction, all the energy which is done on

the spring is available for use when the spring is allowed to contract.

277. We may say, therefore, that the energy stored up in a spring is proportional to the square of the force applied to it.

278. Now in paragraph 69 we defined the expression "flexibility" as being the measure of the amount by which a given spring would be extended for a given force; it follows, therefore, that if in the experiments described above we substitute a spring having twice the flexibility, we shall stretch this more flexible spring a distance of 2 feet by applying 1 lb. of force to it, thus storing in it 2 foot-pounds of energy. Further, we shall stretch it a distance of 4 feet by applying 2 lbs. of force to it, thus storing 8 foot-pounds of energy in it. We may say, therefore, that the energy stored up in the spring is directly proportional to the flexibility of the spring as well as being proportional to the square of the force applied to it.

279. Similarly, if we apply an E.M.F. to a condenser, we cause electricity to flow into the condenser, and the quantity of electricity (which will correspond to the amount by which we stretch a spring) will be directly proportional to the electromotive force applied to the condenser.

280. Thus, if the capacity of the condenser is one farad and an E.M.F. of one volt is applied to it, one coulomb of electricity will be forced into the condenser (*vide* paragraph 70), and assuming for the moment that this force is being exerted throughout the process of charging, it follows that one joule of energy will be stored in the condenser (*vide* paragraph 74).

281. Further, if we double the force applied to the

condenser by applying two volts instead of one, we shall force two coulombs of electricity into the same condenser, and if again we assume that during the whole process of charging, the full force of two volts is being exerted, then in this case it follows that four joules of energy will be stored in the condenser, because we get two coulombs of electricity upon which a force of two volts has been exerted.

282. **We may say, therefore, that the energy stored up in a condenser is directly proportional to the capacity of the condenser and proportional to the square of the voltage applied to it.**

283. Up to the present, however, we have considered for the sake of simplicity that the force exerted is uniform in the case of the spring throughout the process of stretching and in the case of the condenser throughout the process of charging. This, however, is in reality not the case, as will be readily seen by analysing what takes place during the time the spring is being stretched. Taking, for instance, the case of the particular spring which was stretched 2 feet by a force of 2 lbs. This same spring was stretched 1 foot when a force of 1 lb. was exerted on it. Similarly it will be stretched only 6 inches if a force of half a pound were exerted on it, and so on.

284. Obviously, therefore, the total force exerted on the spring in stretching it a distance of 2 feet is not the maximum force of 2 lbs. but the average of all the forces from 0 to 2 lbs.

It will be found that this average force is always half the maximum force, assuming that the force applied at the commencement of the operation is zero.

285. Similarly with a condenser the average force

applied in charging it from zero to a certain voltage will be half that maximum voltage. Therefore, in order to calculate the energy in the joules stored up in a condenser, we must take half of the product of the capacity of the condenser and the square of the E.M.F. to which it is charged in volts. This may be stated as an equation,

$$E = \frac{1}{2} CV^2,$$

where E = energy in joules, C = capacity of condenser in farads and V = voltage to which the condenser is charged.

Power in Oscillatory Circuit

286. In paragraph 75 we explained that Power is Energy expended per second. If, then, after charging a condenser to a certain voltage, during which process we expend so much energy upon it, we discharge that condenser we shall be in a position to recharge it expending the same amount of energy as before. It follows, therefore, that the power used will be the product of the energy expended during a single charge, and the number of times per second that it is charged. We may say, therefore, that

$$\text{Power} = \frac{1}{2} CV^2 \times S,$$

where S is the number of times per second that the condenser is charged.

Open and Closed Oscillatory Circuits

287. A simple oscillatory circuit (*vide* paragraph 251) is shown diagrammatically in Fig. 38. Such a circuit is called a **closed oscillatory circuit.**

288. Another form of oscil'atory circuit is shown in Fig. 39, which represents an aerial wire connected to

earth; the aerial acts as one side of the condenser, the earth acts as the other; the wires forming the aerial also form the inductance.

Such a circuit is called an **open oscillatory circuit.**

289 **The chief difference in the properties** of a closed oscillatory circuit and those of an open oscillatory circuit is that—

An open oscillatory circuit will produce waves having

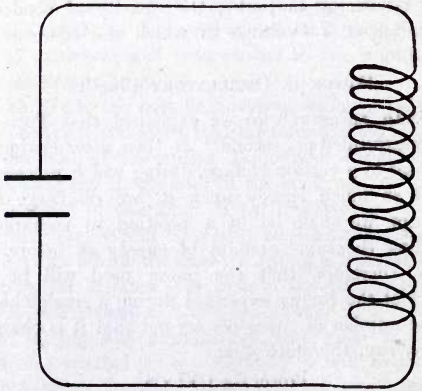


Fig. 38.

a very large amplitude, and is therefore a good radiator, whereas a closed oscillatory circuit will only produce waves of a very small amplitude, and is therefore a very bad radiator.

290. **The chief difference in the composition** of a closed oscillatory circuit and an open oscillatory circuit is that—

In a closed oscillatory circuit the capacity and the inductance are more or less separated from one another,

all the capacity being grouped at one point of the circuit and all the inductance at another; whereas in an open oscillatory circuit the capacity and inductance are, so to speak, mixed up and distributed along the entire length of the circuit. Thus the aerial wire itself is

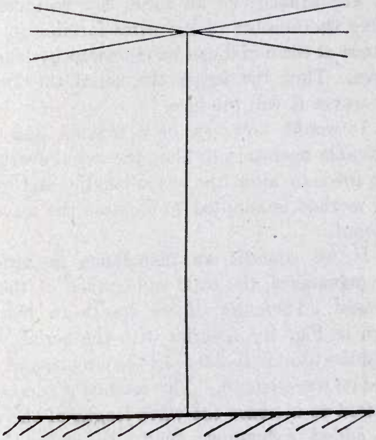


FIG 39.

acting as one plate of a condenser and at the same time as an inductance.

VARIATION OF WAVE-LENGTHS OF OPEN OSCILLATORY CIRCUITS

291. The frequency of the aerial must be adjusted so that it produces electric waves of the desired length (*vide* paragraphs 208 and 257), and this can only be

done by altering the capacity or the inductance of the aerial circuit.

To increase the Wave-length of an Aerial

292. The capacity of an aerial can be increased by increasing the number of the wires forming it, and the inductance of the aerial can be increased by lengthening the wires. Thus the larger the aerial the longer the electric waves it will produce.

293. It would, however, be a tedious, and, in fact, impracticable operation to alter the aerial every time it was required to alter the wave-length, and therefore another method is adopted to increase the wave-length of an aerial.

294. If we connect **an inductance in series with another inductance**, the total inductance of the circuit is increased. Therefore, if we insert an inductance, as shown in Fig. 40, in series with the aerial, we have increased the total inductance of the circuit, and thereby increased its wave-length. This method is adopted when it is desired to increase the wave-length of the aerial.

This added inductance tends to make the open oscillatory circuit of the aerial into a closed oscillatory circuit (*vide* paragraph 290); the more inductance we add the nearer do we approach a closed oscillatory circuit, for although some of the total inductance of the aérial is still, so to speak, mixed up with the capacity, a large part of it is separate.

295. As already stated, a closed oscillatory circuit does not radiate energy to any appreciable extent (*vide* paragraph 289); we therefore reduce the radiating properties of the aerial by adding inductance. There

is therefore a limit to the amount of inductance that can be so inserted into the aerial circuit without seriously affecting its efficiency as a radiator.

In practice it is found that the natural wave-length of an aerial can be about doubled without

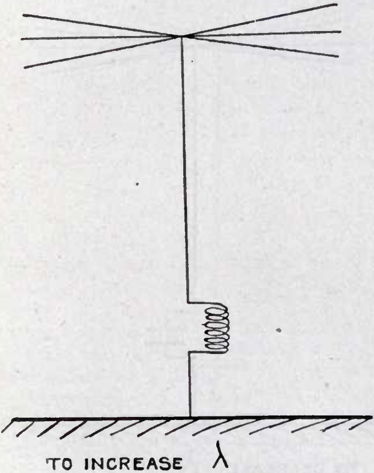


FIG. 40

seriously interfering with the radiation, thus we have a simple means of controlling the wave-length over a comparatively large range.

TO REDUCE THE WAVE-LENGTH OF AN AERIAL

296. If we place a capacity in series with another capacity, the total capacity, instead of being increased, as might at first be imagined, is reduced.

Therefore, if we insert a condenser, as shown in Fig. 41, in series with the aerial, the total capacity is reduced, and therefore the wave-length is also reduced.

297. The amount by which we decrease the capacity depends upon the capacity of the condenser which is

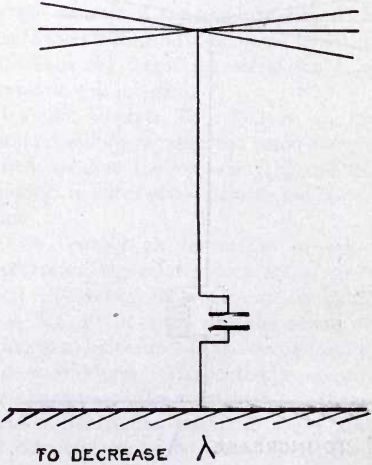


Fig. 41.

inserted in series, and it is important to remember that **the greater the capacity which is inserted in series with another capacity, the less is the reduction of the total capacity**; that is to say, by inserting a small capacity in series with the aerial we reduce the wave-length of that aerial far more than by inserting a large capacity in series with it.

298. Similarly, as in the case of adding inductance, the insertion of a capacity in series with the aerial reduces the radiation of the aerial, but in practice it is found that the natural wave-length of the aerial can be

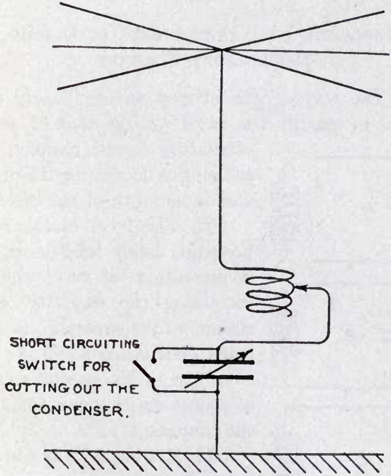


FIG. 42.

about halved by this means, without seriously interfering with the efficiency of the aerial as a radiator.

299. It will be seen, therefore, that by connecting a condenser or an inductance in series with the circuit the length of the electric waves emitted by the aerial can be varied from nearly one-half to double the natural wave-length of the aerial without seriously affecting its efficiency as a radiator.

Fig. 42 shows an aerial with an adjustable condenser; and an adjustable inductance connected to it. Such an aerial is capable of emitting waves of different lengths within the practical limits mentioned above.

Variation of Wave-lengths of Closed Oscillatory Circuits

300. The wave-length of a closed oscillatory circuit is varied in exactly the same way as that of an open oscillatory circuit, namely, by increasing or decreasing the capacity and inductance of the circuit.

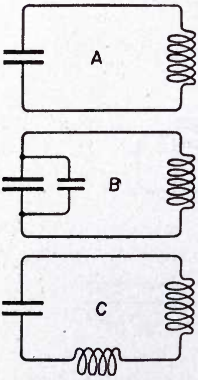


Fig. 43.

301. The form of the circuit, however, lends itself more easily to increasing the wave-length by increasing the capacity of the circuit, as the capacity, instead of being distributed along the whole circuit as in the case of an aerial, is almost entirely concentrated in the condenser.

302. **If a capacity is connected in parallel with another capacity, the total capacity is increased**; thus by connecting an additional condenser in parallel with the existing condenser of a closed oscillatory circuit we increase the wave-length of that circuit.

303. Fig. 43 shows different methods of increasing the wave-length of a closed oscillatory circuit.

A represents the original circuit. B represents the same circuit with an additional capacity connected in

parallel, thus increasing the total capacity and thereby increasing the wave-length. C represents the same circuit with an additional inductance connected in series, thus increasing the total inductance of the circuit and thereby increasing the wave-length.

304. Fig. 44 represents different methods used for reducing the wave-length of a closed oscillatory circuit.

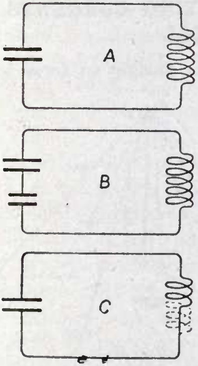


FIG. 44

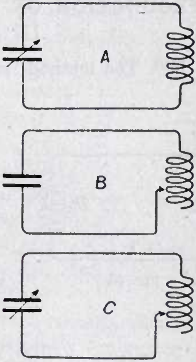


FIG. 45

A represents the original oscillatory circuit. B represents the same circuit with an additional condenser connected in series with it, thus reducing the total capacity of the circuit and thereby reducing the wave-length. C represents the same circuit with some of the inductance cut out, thus reducing the total inductance in the circuit and thereby reducing the wave-length.

305. The methods above described are only used where a definite jump from one definite wave-length to another is required. If intermediate wave-lengths are

required, it is usual to make either the condenser or the inductance adjustable, as shown in Fig. 45, where A represents a circuit in which only the capacity is adjustable, and B represents a circuit in which only the inductance is adjustable ; C represents a circuit in which both the capacity and the inductance are adjustable.

PRODUCTION OF OSCILLATING CURRENTS IN AN AERIAL

306. The methods employed for causing an aerial to

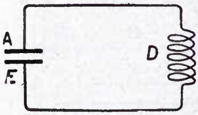


FIG. 46.

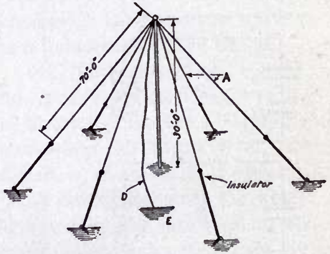


FIG. 47.

oscillate, and thus radiate electric waves, fall under two headings, viz. **Direct Excitation** and **Indirect Excitation.**

DIRECT EXCITATION OF THE AERIAL

307. We have already explained that an aerial connected to earth is an oscillatory circuit, and therefore, for convenience in explanation, we may consider it as a condenser with its two plates connected by an inductance, as shown in Fig. 46, the aerial wires A, Fig. 47, corresponding to one plate of the condenser A, Fig. 46; the

earth E, Fig. 47, corresponding to the other plate of the condenser E, Fig. 46; and the connecting wire or "down-lead" D, Fig. 47, corresponding to the inductance D, Fig. 46.

308. It has already been explained (paragraph 237) that if a condenser be charged up and then short-circuited through an inductance, the charge of electricity will not immediately come to rest, but the condenser will over-discharge itself, and the current will oscillate backwards and forwards until, owing to the resistance of the circuit and the radiation of energy, the charge of electricity comes to rest.

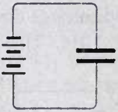


FIG. 48

309. In order to excite an oscillatory circuit, such as is shown in Fig. 46, it is therefore only necessary to give the condenser an initial charge of electricity, by applying a "voltage" or pressure of electricity across it, and then allow it to discharge itself through an inductance.

Let us now see how this can best be accomplished.

310. We can charge up a condenser by connecting a battery across it, as shown in Fig. 48, which will charge the condenser up to the same voltage as the battery; but in applying a voltage in this way to a condenser, whose two plates are connected together through an inductance to form an oscillatory circuit, as shown in Fig. 46, the electricity, instead of charging up the condenser as desired, will simply flow through the inductive winding D.

311. It is therefore obvious that during the time the condenser is being charged, we must break the circuit through the inductive winding, as shown in Fig. 49 at the point marked S.

312. This, however, destroys the oscillatory circuit, as it prevents the discharge of the condenser through the circuit D, which discharge is required to produce the oscillations.

313. In order, therefore, to get the conditions right, both for charging up the condenser and for discharging it through the circuit D, it would be necessary to devise some form of mechanism for automatically breaking the discharge circuit and connecting the battery to the condenser at one moment, and then "making" the discharge circuit at the next moment.

314. This method, however, is impracticable, as, apart from the fact that it would be somewhat complicated in operation, an additional drawback arises inasmuch as a very large battery would be necessary in order to charge the condenser up to a sufficiently high voltage to store up the energy that is required to obtain a useful range of transmission.

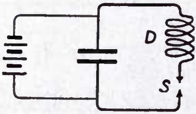


FIG. 49.

315. In paragraph 286 we showed that the power put into a condenser depends upon three things, namely, the capacity of the condenser, voltage to which it is charged, and the number of times per second that it is charged. Obviously, therefore, the power in the oscillatory circuit is also equal to $\frac{1}{2}\,CV^2 \times S$, but in this case S will be the number of times per second that the condenser is discharged into the oscillatory circuit.

316. As already explained (paragraph 291), the capacity of the aerial is limited by the wave-length it is desired to produce.

Further, the number of times per second it can

be charged and discharged is limited by other practical considerations, which will be dealt with later.

317. It follows that the only method we have of increasing the power in the oscillatory circuit we are considering, namely, an aerial, is by increasing the voltage applied to the condenser.

Let us take, for example, a small "umbrella" aerial supported by a mast 30 feet high, the length of the radial wires forming the aerial being 70 feet long, as shown in Fig. 47. The capacity of such an aerial would be about ·0005 microfarad.

318. Assuming that our automatic device for charging and discharging the aerial is capable of doing it at the rate of 100 times per second, it can be shown that the initial voltage to which such an aerial would have to be charged in order to radiate 10 watts of power would be about 20,000 volts, assuming that all of the power is expended in radiation and none lost in the resistance of the aerial circuit.

The impracticability of the method described above becomes obvious, as it would require a battery of about 14,000 dry cells, or 10,000 accumulator cells, to obtain this voltage.

319. A very much simpler method of exciting an oscillatory circuit presents itself by making use of the properties of a spark gap in conjunction with an induction coil (described in paragraph 118 onwards)

320. **Air in its normal state is nearly a perfect insulator**; that is to say, for all practical purposes it will not conduct electricity. If, however, a sufficiently high voltage is applied across an air space the insulation of the air is broken down, allowing the current to pass through the air space, causing a spark to occur, and the

effect is to make the air space momentarily into a conductor.

Further, once the spark is formed it will be maintained by a very small current, but as soon as the succession of sparks ceases the air space returns to its normal state of insulation.

321. By applying this phenomenon to the oscillatory circuit, as shown in Fig. 50, we get conditions such that **during the time that the condenser is being charged** the path through the inductive winding is broken by the air-gap, but **as soon as the voltage across the condenser rises to a certain maximum, depending upon the length of the air-gap**, the insulation of the air-gap is broken down, a spark occurs across it, and for the moment the gap, instead of being an insulator, becomes a conductor, and allows the condenser to discharge itself through the oscillatory circuit.

322. As already explained, the condenser not only discharges itself, but over-discharges itself, and the current oscillates backwards and forwards a number of times, until, owing to the resistance of the circuit and the radiation of the energy in the form of waves, the oscillations die down, and the current flowing is not sufficient to maintain the spark. The spark then goes out and the air-gap assumes its normal insulating properties until the next high-voltage impulse is applied to the condenser, when the same cycle of events takes place.

323. Such an arrangement is shown diagrammatically in Fig. 50, where A is the impulsive high-voltage generator, B is the condenser, C is the inductance, and D the spark-gap.

324. This method of excitation can be applied to a closed oscillatory circuit, as already shown, or it can be

applied to an aerial by connecting the spark-gap between the aerial and earth, as shown in Fig. 51.

325. An aerial directly excited in this manner is usually called "**plain aerial**," and is extremely efficient

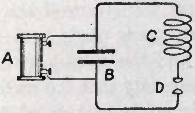


Fig. 50.

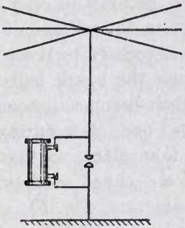


Fig. 51.

for obtaining a comparatively long range with the use of a small power.

COUPLED OSCILLATORY CIRCUITS

326. We have seen how an oscillatory circuit can be energised by charging up a condenser to a high voltage by means of an induction coil and allowing it to discharge through an inductance and air-gap. Referring to Fig. 50, we see that the right-hand part of the diagram is drawn in thick lines. This is a convenient way of denoting **the oscillatory portion** of the circuit, and as—especially in complicated diagrams—it is of great importance to distinguish between the oscillatory circuits and the "low-frequency" circuits, such as the induction coil windings and leads, the reader is advised to follow this plan throughout.

327. Looking at Fig. 50 it may be asked, how can the

thick lines be said to form a "circuit" at all since there is a distinct gap D? A little thought will show us that the gap is only a break in the circuit while the condenser is being charged up by the coil, during which time there are no oscillations and the circuit is not oscillatory; but when the voltage of the condenser has reached the value necessary to break down the insulation of the air between the spark balls a spark takes place, and the gap then becomes a conductor, and the circuit is truly a closed one; **it is during this time only that the oscillations take place,** so that the circuit is completed and forms a "closed oscillatory circuit." Similarly, in the next diagram, Fig. 51, when the spark takes place the circuit is completed and forms an "open oscillatory circuit."

Factors limiting the Power in Oscillatory Circuits

328. Speaking in general, we may say that **the ultimate factor limiting the power we are able to supply to any oscillatory circuit by any given method is the wave-length to which the oscillatory circuit must be adjusted.**

329. We have seen that the power which can be put into any oscillatory circuit depends upon three factors, namely:

(1) The number of times per second that the condenser is charged;

(2) The voltage to which the condenser is charged; and

(3) The total capacity of the condenser.

We find that all these factors are limited by practical considerations.

330. **Taking the first factor,** namely, the number of

times per second that the condenser is charged, we shall show later that **the note produced in the telephones of the receiving station is the same frequency as the frequency of the spark of the transmitting station.**

331. This is called the **spark frequency**, and must not be confused with the oscillation frequency (*vide* paragraph 257), of which it is absolutely independent.

332. The human ear cannot hear a note whose frequency exceeds a certain value, about 15,000 per second, but before this limit is reached another practical difficulty arises, namely, the mechanical construction of a generator to produce such a high frequency.

333. **Taking the second factor**, namely, the voltage to which we charge a condenser, we find we are limited here in several directions.

334. In the first place, if the oscillatory circuit we are energising is an aerial, the mere fact of charging it to a very high potential is in itself bad, for at a certain voltage the ends of the wires begin to " brush " and discharge electricity to the surrounding air, causing a considerable loss of energy. This phenomenon can sometimes be seen at night at the ends of an aerial wire, which appear to be surrounded by a bluish glow.

335. Secondly, the difficulty of maintaining a sufficiently good insulation of the aerial to withstand such a high voltage becomes very serious, especially in wet weather.

336. Thirdly, to charge up the condenser in an oscillatory circuit to a high voltage necessitates using a long air-gap in the oscillatory portion of that circuit so that it may not break down until a high voltage is reached. Although, as we have said, the air becomes momentarily a conductor when the spark is passing, yet,

like all conductors, it has a certain resistance, and this resistance increases very rapidly with the length of the gap.

337. As we have already shown, the introduction of resistance in an oscillatory circuit causes a waste of energy and a rapid dying away of the oscillations. For this reason the use of extremely high voltages in oscillatory circuits, necessitating, as it does, a long spark-gap, leads to inefficiency.

338. **Taking the third factor**, namely, the total capacity of the condenser, we find that an increase in the capacity in any oscillatory circuit will necessarily increase the length of the wave, unless a corresponding decrease is made in the inductance of the circuit (*vide* paragraph 256).

339. We find, however, that in a closed oscillatory circuit we can reduce the inductance (and therefore increase the capacity) to a far greater extent than we can in an aerial.

340. In the case of an aerial we can increase the capacity by bringing the aerial nearer the ground, and thus reducing the thickness of the dielectric (*vide* paragraph 19), but this decreases the range we can obtain.

341. We can also increase the capacity of an aerial by increasing the length of the wires forming the aerial, but this at the same time increases the inductance in the wires, and therefore increases the wave-length.

342. The only other way of increasing the capacity of an aerial is to increase the number of wires forming it. This, however, will not increase the capacity sufficiently for our purpose, and, moreover, tends to make the aerial costly and unwieldy.

343. As already pointed out, however, in the case of

a closed oscillatory circuit, the proportion of the capacity to the inductance of the circuit for a given wave-length can be made far greater than in the case of an aerial, and therefore we can make such a circuit capable of utilising **a larger amount of power for the same wave-length, the same spark frequency, and the same voltage.**

344. A closed oscillatory circuit, however, is not a good radiator (*vide* paragraph 289), and is therefore not a good substitute in this respect for the open oscillatory circuit provided by the aerial. **If, however, we can combine the good energy-storing property of the closed oscillatory circuit and the good energy-radiating property of the aerial, we shall obtain the best results for a limited wave-length.**

345. This is the plan on which is based the "coupled-circuit" transmitter now in general use, a diagram of which is shown in Fig. 52.

346. The closed oscillatory circuit X (Fig. 52) is excited in the way described in paragraph 319. The oscillating currents set up pass to and fro round the circuit, which includes a coil L, consisting of one or more turns of wire. This coil is so placed with respect to another coil N connected in the aerial circuit that the two coils exercise mutual induction (see paragraph 114) on each other. One end of this second coil is connected to the aerial A, and the other end to earth E. The oscillating currents flowing through L create, **through the mutual inductance of the two coils**, oscillating currents in the aerial.

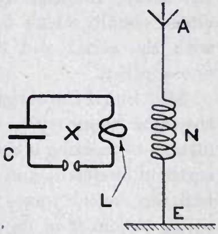


Fig. 52.

347. If, however, the values of capacity and inductance of the aerial circuit are arranged so that the aerial has a frequency different from that of the closed circuit, the aerial will try to oscillate at its own frequency (*vide* paragraph 252) in opposition to the oscillations put into it by the closed circuit, with the result that one set of oscillations will interfere with the other, and very little energy will be transferred from the closed to the open circuit. Under these conditions the two circuits are said to be "**out of tune.**"

348. To understand what happens when the circuits are out of tune, we may take it that the first oscillation in the closed circuit induces a wave in the aerial coil; this wave travels up the aerial, reaches the free insulated end, turns back and tries to return to earth; but on its way there it meets another wave coming up the aerial, induced by the second oscillation in the closed circuit, which is not "keeping time" properly with the aerial, and these two waves partly destroy one another.

349. But if the aerial circuit is so arranged as to have the same frequency as the closed circuit, the first wave, instead of meeting a contrary wave, will travel down to earth unhindered, and as it swings back again it will find the second wave, induced from the closed circuit, ready to join it in its progress up the aerial and down again to earth; and this will go on, one wave adding on to the others already in the aerial, until the condenser C is discharged; that is to say, **until the energy originally stored up in the closed oscillatory circuit is transferred to the aerial.** Under these conditions the two circuits are said to be "**in tune.**"

350. We may say, then, that in order to excite

efficiently one oscillatory circuit from another in which oscillating currents are flowing, **it is necessary that the two circuits have the same frequency.**

351. A simple experiment can be made with pendulums to illustrate this point. A piece of string is stretched between two fixed points (Fig. 53), and two pendulums, P_1 and P_2, are hung from it a short distance apart.

352. Now if these pendulums have the same time of

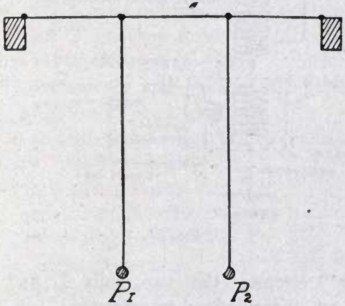


Fig. 53.

swing, and therefore the same frequency, they may be said to be in tune, and it will be found that if P_1 (which may be taken to represent the closed oscillatory circuit) be started swinging, it will, owing to its being coupled to P_2 by the string, gradually start a similar swing in P_2.

353. The swing in P_2 will get greater and greater until the energy that was originally put into P_1 is transferred to P_2, and P_1 will have come to rest.

354. If, however, P_2 be made shorter or longer than

P_1, so as to have a different frequency, the two pendulums may be said to be **out of tune**, and it will be found that, although a certain amount of swing will be induced in P_2, the two pendulums will interfere with one another, and both will come to rest after erratically jerking about.

355. The closed oscillatory circuit is spoken of as the

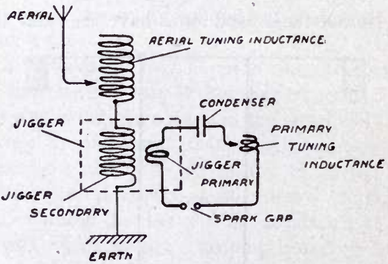


Fig. 54.

"**primary**" **circuit**; the two coils L and N form together an "**oscillation transformer**" or "**jigger,**" the coil L being the "**jigger-primary,**" and the coil N the "**jigger-secondary.**"

356. In order to "**tune**" the primary circuit to the aerial, it is usual to connect a "**variable inductance**" both in the aerial circuit and in the primary circuit, as shown in Fig. 54. Such an inductance in the primary circuit is called the "**primary tuning inductance,**" and in the aerial circuit is called an "**aerial tuning inductance.**"

The Auto-jigger

357. In the above method of indirect excitation we had two entirely separate circuits, the primary circuit and the aerial circuit, connected only by the mutual induction of jigger-primary and jigger-secondary; and we saw that, provided each of these two circuits was tuned to the same wave-length, the arrangement offered us an excellent combination—a good storer of energy combined with a good radiator of energy.

358. There is another form of indirect excitation, using what is called an "**Auto-jigger,**" which at one time was fairly extensively used, and is still popular among amateurs owing to its simplicity.

359. In an auto-jigger we still have the two circuits—the primary circuit with its condenser and jigger-primary, and the aerial circuit with its aerial, its tuning inductance, its jigger-secondary, and its earth, and these must be tuned to the same wave-length just as in the case of the ordinary jigger, but in the case of the auto-jigger **the primary circuit is in actual metallic connection with the aerial circuit**; in fact, the jigger-primary is formed of a certain number of turns of the jigger-secondary itself.

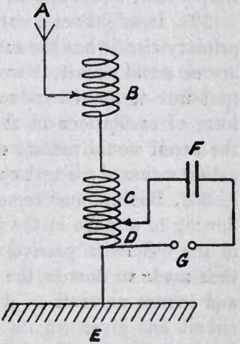


Fig. 55.

360. Thus in Fig. 55, which illustrates the auto-jigger, the aerial circuit consists of the aerial A, the

aerial tuning inductance B, the jigger-secondary CD, and the earth connection E; while the primary circuit consists of the condenser F, the spark-gap G, and the jigger-primary D, which is merely a certain number of turns of the jigger-secondary CD.

361. With such an arrangement we have the same advantage as with the ordinary jigger—namely, a good storer of energy (the closed oscillatory circuit containing the large condenser F) transferring its energy, through the action of the coil D, to the good radiator, the open oscillatory circuit A, B, C, D, E,

Reaction of Secondary on Primary

362. The behaviour of a coupled-circuit transmitter, whether an ordinary jigger or an auto-jigger, is less simple than would appear at first sight.

363. It might seem natural to suppose that since the primary circuit has the same wave-length as the secondary or aerial circuit, it would simply transfer its energy (put into it by the induction coil) to the aerial in the form of oscillations of the same frequency; and that the aerial would radiate out this energy in the form of aether waves of a length corresponding to that frequency.

364. But we must remember that just as the currents flowing to and fro in the jigger-primary induce currents in the otherwise passive secondary, **so do the currents thus made to flow in the secondary act on the primary and induce currents in it**; so that when the primary circuit has given up its energy to the secondary the latter starts giving back some of its energy to the primary, which returns it to the secondary, and so on.

365. This goes on till so much energy has been removed from the circuits—by losses in resistance and by

radiation from the aerial—that the current in the primary has no longer power to cross the spark-gap, when the process stops until it is started again by the induction coil charging up the condenser once more.

366. This will be more easily understood by referring again to the pendulum experiment described in paragraph 351.

367. In this paragraph we only followed the action of the pendulums up to the moment when the driving pendulum P_1 had transferred its energy to P_2, but if we watch their action still further **we see that P_2 now becomes the driving pendulum**, and its energy will gradually be transferred back to P_1, and this transfer of energy goes on backwards and forwards until so much energy has been lost in friction in the air and string that both pendulums come to rest.

Now this rather complicated give-and-take process has a peculiar effect on the wave set up in the aerial.

368. **The result of coupling a closed oscillatory circuit to an open oscillatory circuit, each of which is tuned to the same wave-length, is the production of two wave-lengths, one longer and the other shorter than the wave-length to which both circuits have been tuned.** These two wave-lengths are known as the **Resultant Wave-lengths.**

369. It is not an easy subject to understand, but it is a very important one, and our readers are recommended to take pains to master it.

Resultant Wave-lengths of Coupled Circuits

370. The jigger-primary has a certain amount of inductance (which has already been defined) due entirely to itself—its number of turns, its diameter, the spacing

of its turns, etc.; this is called the **self-inductance of the primary.**

371. Similarly the jigger-secondary has a certain self-inductance, due to its number of turns, diameter, spacing of turns, etc.

372. But besides these two self-inductances, which would remain unaltered if the primary were taken to the Equator and the secondary kept at home, there is a third inductance which affects both primary and secondary, and which is due to the proximity of the one coil to the other.

373. **This is called the mutual inductance**; thus the primary has, in addition to its self-inductance, the mutual inductance due to the effect of the secondary, and the secondary has, in addition to its self-inductance, the mutual inductance due to the presence of the primary.

374. This **mutual inductance depends on the position of the primary with regard to the secondary,** on their distance apart, and on the number of turns acting on each other.

375. The mutual inductance of two such coils, though it is an abstract kind of thing which cannot be seen, is nevertheless a definite quantity, and is very important, as it is through the agency of the mutual inductance that the primary circuit is able to transfer its energy to the aerial circuit.

376. By making a simple experiment with two coils of wire, we can demonstrate what is the effect of the mutual inductance of the two coils on the total self-inductance of the coils.

377. Let us suppose that we have two separate coils A and B, each consisting of two turns as shown in Fig. 56, placed at such a distance apart that none of the

magnetic lines of force produced by a current flowing through A pass through the coil B, and, therefore, also none of the lines of force produced by B pass through A. If now we connect the two coils in series, as shown, and pass a current through both of them, a certain number of

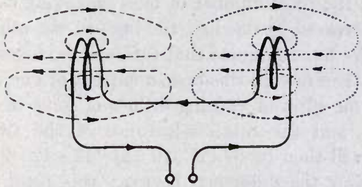


FIG. 56.

lines of force will be induced by the coil A, and an equal number will also be induced by the coil B.

378. Now the inductance of a coil is proportional to the number of lines which thread it, when unit current flows through that coil, multiplied by the number of turns in the coil (assuming that all the lines of force produced by the coil thread all the turns). Thus, if we assume that the coils A and B each consist of two turns, and that when a current of one ampere flows through them four lines of force are produced by each coil, then the inductance of each coil will be $4 \times 2 = 8$, and under these conditions the total inductance of the two coils together will be $8 + 8 = 16$.

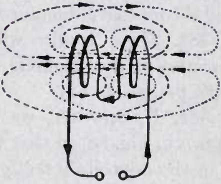


FIG. 57.

379. Let us now suppose that the two coils be placed

rather closer to one another, as shown in Fig. 57, so that half of the lines produced by coil A also thread the coil B, and also half of the lines of the coil B thread the coil A. Then it is evident that, when a current of one ampere flows through the two coils, although each coil individually produces the same number of lines as before, the total number of lines threading each coil will be increased by one half the lines in the other coil.

380. We have assumed that each coil produces 4 lines of force; therefore, in this case, a current of one ampere *will have the effect* of causing 6 lines of force to thread each coil, and the total inductance of the two coils together will then be $(6 \times 2) + (6 \times 2) = 12 + 12 = 24$.

381. Now the difference between this total inductance and the total inductance of the two coils, when a great distance apart, is the mutual inductance of the two coils. That is to say, in the case illustrated, in Fig. 57, mutual inductance $= 24 - 16 = 8$.

382. Similarly, it will be found that if the two coils are placed so close together that all the lines induced by each coil individually thread the other coil, the total inductance of the two coils together will then be 2 (turns) $\times$ 8 (lines) + 2 (turns) $\times$ 8 (lines) $= 16 + 16 = 32$, and the mutual inductance in this case will be $32 - 16 = 16$.

383. These results will be obtained, provided the direction of the magnetic lines is the same in both coils (*vide* paragraph 82).

384. If, however, we connect up the two coils as shown in Fig. 58, so that the current flowing in one coil is in the opposite direction to that flowing through the other coil, thus inducing magnetic lines in one coil in the opposite direction to the magnetic lines in the other, then different results will be obtained when the two

coils are brought together, because the magnetic field produced by one coil will *tend to neutralise* the magnetic field produced by the other coil.

385. When the two coils are remotely separated, as

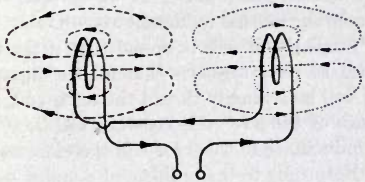


FIG. 58.

shown in Fig. 58, so that none of the lines of force induced by A pass through B, and *vice versa,* then the total inductance of the two coils will be the same as in the case illustrated in Fig. 56, namely 16. But when the two coils are placed closer to one another, as shown in Fig. 59, so that two lines produced by each coil thread the other, then these two lines being in the opposite direction will neutralise two of the lines induced by that coil, so that in this case a current of one ampere *will have the effect* of causing only two lines of force to thread each coil, and, therefore, the total inductance of the two coils together will then be $(2 \times 2) + (2 \times 2) = 8$.

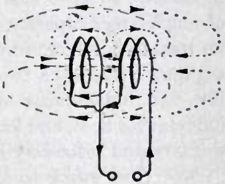


FIG. 59.

386. Now the difference between this total inductance and the total inductance of the two coils when a great distance apart, as shown in Fig. 58, that is to say $8 - 16$,

will again represent the mutual inductance of the two coils, which it will be seen is the same value, *but opposite in sign* to the value of the mutual inductance, when the two magnetic fields were in the same direction. In that case the mutual inductance, as we showed, was +8. In this case the mutual inductance is −8.

387. Similarly, it will be found that if the two coils are placed so close together that all the lines induced by each coil individually thread the other coil, the total inductance of the two coils together will be 0, and the mutual inductance in this case will therefore be −16.

388. Returning to the problem of coupled oscillatory circuits, we can now follow the effect of the mutual inductance on the resultant wave-length.

Let us suppose, for the sake of simplicity, that the self-inductance of the primary circuit is equal to that of the secondary circuit; we know that the wave-lengths of the two circuits are the same, but as a rule the inductance of the primary is much less than that of the secondary, so as to enable the primary condenser to be of much larger capacity than that of the aerial; there is no reason, however, why we should not, for the sake of argument, make the two capacities equal, and therefore the two inductances also equal. Let each of these inductances be L, and let the mutual inductance between primary and secondary be M.

389. Now owing to the give-and-take process which we described above, the relative directions of the oscillatory currents flowing in the primary and secondary coils are continually changing with this result: it makes the mutual inductance M add itself to the self-inductance L at one moment, and then, a fraction of a second later, it makes M subtract itself from L. The result is that at the

first moment each circuit behaves as if its total inductance were L + M, and at the next moment as if it were L − M. But these moments are so close together—separated only by such an infinitely small fraction of a second—that what happens is **that the circuits appear to possess these two values of inductance at the same time**; so that they behave as if, instead of each having an inductance L, they each had two different inductances, L + M and L − M.

390. But if a circuit has two inductances and one fixed capacity, it is clear that it will give two wave-lengths; and, as a matter of fact, the result of the give-and-take action between primary and secondary is that **the aerial sends out two waves, one longer and one shorter than the wave to which both the primary and aerial circuits were tuned.**

391. It is clear that the production of these two waves is governed by the size of M compared with L; if we make M very small compared with L by increasing the distance between the primary and secondary of the jigger, L + M will only be very slightly larger than L − M, so that the two waves will be so nearly equal as to be indistinguishable.

392. So if we move the jigger-primary farther and farther away from the jigger-secondary, we can reduce M and make the two waves approach nearer and nearer to one another, till finally they merge into one wave-length which will be of the same value as that of the circuits taken by themselves.

393. We assumed, for the sake of simplicity, at the beginning of paragraph 388, that the inductance of the primary was equal to that of the secondary. If, as is usual, these inductances are different, the same thing

holds good, except that the simple formula of $L+M$ and $L-M$ becomes somewhat more complicated and elaborate.

394. To summarise we may say that:

(1) Two oscillatory circuits can be coupled together for the purpose of exciting one from the other.

(2) The two circuits must be both tuned to the same wave-length.

(3) The result is the production of two distinct waves, one longer and one shorter than the normal wave-length of either circuit taken separately.

(4) The closer two circuits are coupled together the greater the difference between the two resulting wave-lengths.

Calculation of the Degree of Coupling

395. For convenience the degree of coupling between two oscillatory circuits is expressed as a percentage of the full coupling.

A large degree of coupling is known as a "close coupling," and a small degree of coupling as a "loose coupling."

396. If two oscillatory circuits were fully coupled the two resulting waves would be so far apart that the lower wave would be sensibly zero, and the only wave-length left would be $\sqrt{2}$ or 1·4 times the wave-length of the two circuits taken separately.

397. In practice such conditions cannot be obtained, because even if the primary and secondary coils were so close together that all the lines of force induced by the primary coil threaded the secondary coil, and *vice versa,* these are not the only lines of force induced by each circuit.

398. For instance, the currents flowing through the conductors which connect the primary coil to the condenser and through the primary tuning inductance, induce lines of force round those conductors which do not thread any part of the secondary circuit; similarly, the currents flowing through the radiating portion of the aerial, as well as through the aerial tuning inductance coil, induce lines of force which do not thread any part of the primary circuit.

399. Since the degree of coupling is the proportion of the number of lines which thread the other circuit to the total number of lines induced, it is obvious that a full coupling between the primary circuit and the aerial is impossible. These conditions will be more clearly understood by referring to Fig. 60, which shows diagrammatically the distribution of the lines of force induced in the two circuits.

400. It will also be seen that the greater the amount of tuning inductance that is inserted in either the primary or secondary circuit, the less will be the degree of coupling between the two circuits, unless these inductances be so arranged relatively to one another that the lines of force induced by the currents flowing through them thread the inductance coils of the other circuit.

401. It is evident that *any "outside." inductance* (*i.e*, any inductance which is not mutually acting on the other circuit) *included in either the Primary or the Secondary circuits is tending to weaken the coupling obtainable between the two circuits.*

It is not, however, necessarily an advantage to have a close coupling between the two circuits, and in fact too close a coupling has many disadvantages.

402. In practice, it is usual to allow for a maximum

coupling of 15 per cent or 20 per cent between the primary circuit of the transmitter and the aerial circuit, and where very sharp tuning is required this coupling

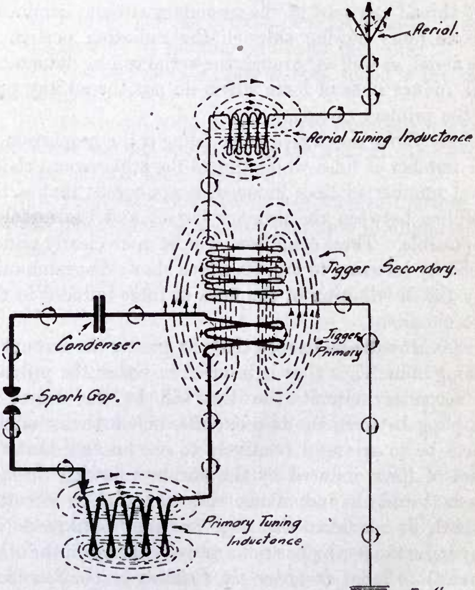


Fig. 60.

is frequently reduced to 1 per cent or 2 per cent, by methods described later.

403. As a matter of fact, with commercial stations, a regulation has been laid down by the International

Wireless Convention that no station is allowed to use a closer coupling than 15 per cent.

404. Since the difference between the two resulting wave-lengths of coupled circuits depends upon the degree of coupling between the circuits, it follows that we can calculate the coupling if we know the values of these two waves, and the following formula, although not exact, will give a very near approximation of the percentage of coupling.

405. If k = percentage of coupling between two circuits, and λ_1 is the wave-length of the longer of the two resulting waves, λ_2 the wave-length of the shorter of the two resulting waves, and λ_0 the wave-length of each of the circuits taken separately, then

$$k = \frac{\lambda_1 - \lambda_2}{\lambda_0} \times 100 \text{ (approximately).}$$

406. Let us apply this formula to a practical case.

On a certain vessel a wireless installation had been fitted. The wave-length of the closed oscillatory circuit was adjusted to 600 metres, and that of the aerial circuit to the same. When the primary oscillatory circuit was coupled to the aerial it was found that the resulting wave-lengths were 570 metres and 630 metres respectively.

From this it can be calculated that the coupling between the two circuits was 10 per cent, for—

$$k = \frac{630 - 570}{600} \times 100$$
$$= 10 \text{ per cent}$$

Methods of varying the Coupling between two Oscillatory Circuits

407. Many different ways are employed for varying the coupling between the inductive windings of two oscillatory circuits; all of them, however, are based on the principle of varying the proportion between the number of lines induced by one coil, which thread the other coil, and the total number of lines induced.

408. The method most commonly used to vary the coupling between the primary circuit and the aerial circuit of a transmitter **is to slide the secondary winding away from the primary winding.**

This method is illustrated in Figs. 61 and 62, where A is the inductive winding of the open oscillating circuit, that is to say, the jigger-secondary, and B the inductive winding of the closed oscillating circuit, that is to say, the jigger-primary.

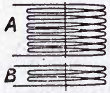


Fig. 61.

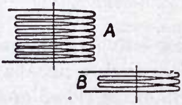


Fig. 62.

409. When one of these two coils is immediately above the other, as shown in Fig. 61, the coupling between the two is at its maximum, but when the secondary winding is moved until it occupies a position near the edge of the primary winding, as shown in Fig. 62, the coupling is at its minimum.

410. Another method of adjusting the coupling between two circuits **is to alter the relative angular position between the axes of the two windings.**

When these two axes are in line the coupling is at its maximum, and when they are at right angles to

one another the coupling is at its minimum. In this case the lines of force induced by the one coil do not thread the other coil, but pass along the conductors.

This method is illustrated in Figs. 63 and 64. In Fig. 63 the axes of the two coils are in line, and the coupling is at its maximum, whereas in Fig. 64 the axes of the two coils are at right angles to one another, and the coupling is at its minimum.

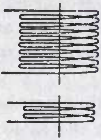


FIG. 63.

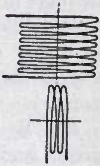


FIG. 64.

THE WAVEMETER

411. The Wavemeter is an instrument for measuring the frequency and therefore the length of the wave or waves emitted by oscillatory circuits.

412. Briefly, it consists of a closed oscillatory circuit whose wave-length, or more strictly speaking, frequency, it is possible to vary, connected to a detector, by means of which it is possible to tell the comparative amount of current flowing in the oscillatory circuit.

413. To measure the wave-length of an oscillatory circuit, the instrument is brought sufficiently near some part of that circuit, so that the oscillating currents flowing in it will induce similar currents in the oscillatory circuit of the Wavemeter.

414. In paragraph 346 we showed that when two oscillatory circuits are coupled together, one of which is set oscillating, similar oscillations are induced in the second circuit, provided that the two circuits are in tune; that if they are out of tune, although a certain amount

of current is still induced in the second circuit, this current will be comparatively feeble and erratic, but will rapidly rise as the circuits are brought nearer and nearer into tune, reaching a maximum when the two circuits are quite in tune.

415. When we bring the wavemeter near another oscillatory circuit, we are in effect coupling the two circuits together, and we shall obtain similar phenomena.

416. By adjusting the frequency of the wavemeter circuit, and at the same time noting, by means of the detector, the comparative amount of current induced into it, we can tell exactly when the wavemeter circuit is in tune with the circuit we are measuring, for when the circuits are in tune the current will be strongest. If we know the value of the wave-length, to which the wavemeter circuit is adjusted, it follows that **this wave-length is also the wave-length of the circuit we are measuring.**

The Oscillatory Circuit of a Wavemeter

417. In practice it is usual to vary only the capacity of the circuit, keeping the inductance a constant value throughout. This for various practical reasons is found to be more convenient than adjusting the inductance. Fig. 65 shows such an oscillatory circuit, where L is the fixed inductance and C the variable condenser.

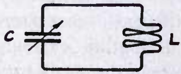


Fig. 65.

418. We have already learnt that the wave-length of an oscillatory circuit depends upon the product of the capacity and the inductance of that circuit: it follows, therefore, that such a circuit can be "tuned up," or, in other words, adjusted to the same frequency as

that of the circuit whose wave-length it is required to measure.

419. Practical considerations limit the maximum and minimum values of the capacity to which the condenser can be adjusted, and therefore limit the maximum and minimum wave-lengths to which the circuit can be tuned.

420. An illustration of a variable condenser is shown in Fig. 66. The principle on which it is constructed will be described later, but for the present it is sufficient to know that its capacity is varied by turning the handle A. Fixed to this handle is a pointer B, which passes over a scale C. This scale is carried half-way round the circumference of the condenser, and is divided into a number of equal divisions which are marked from 0 to 100. When the handle of the condenser is so turned that the pointer indicates the figure 0, the capacity of the condenser is at its minimum, and as the pointer passes up the scale the capacity of the condenser increases until it arrives at its maximum capacity when the pointer indicates the figure 100.

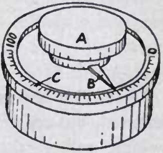


FIG. 66.

421. When this condenser forms part of an oscillatory circuit, the inductance of which is fixed, as in the case of the wavemeter, it follows that **the wave-length of the circuit will have a definite value for every definite position of the condenser pointer.**

422. These wave-lengths are carefully and accurately measured after the instrument is made (by methods which for the purpose of this book it is unnecessary to explain), **and a list or chart is supplied with the instru-**

ment giving the wave-lengths of the circuit corresponding to each scale reading of the condenser.

423. By the use of this chart we can find out to what wave-length the instrument has been adjusted by referring first to the condenser reading and then reading off the chart the value of the wave-length corresponding to that condenser reading.

The "Detector" Circuit of a Wavemeter

424. In order to tell when the wavemeter circuit is in tune with the other circuit, we must find a means of measuring the current in the wavemeter circuit (*vide* paragraph 416).

425. **It is not necessary to know the actual value of the current, but only its comparative value,** so that a detector which will respond proportionally to the amount of current passing through it will suit our purpose.

426. The telephone receiver is a very suitable instrument for this purpose; for one thing, it is extremely sensitive to even the smallest current passing through it, and for another thing, by judging the loudness of the sound in the telephone we can judge the comparative amount of current passing through it.

427. **High-frequency Oscillating Currents, however, will not affect the telephone receiver,** as the alternations are much too rapid for the diaphragm to follow.

428. So that, to enable us to detect the high-frequency currents produced in the wavemeter, these currents, or at all events that part of them which is made to pass through the telephones, must be rectified, or, in other words, converted into uni-directional currents.

THE USE OF CRYSTALS

429. It is found that certain crystals, such as carborundum, have the property of rectifying high-frequency oscillating currents. They really act as non-return valves, allowing the current to pass through them in one direction only, which is equivalent to converting the high-frequency current into a uni-directional current.

430. These crystals, however, have an extremely high resistance, and for this reason cannot be inserted directly in the oscillatory circuit. A little thought, however, will show us that it is not necessary to insert either the crystal or the telephones in the oscillatory circuit.

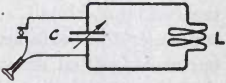


FIG. 67.

431. The current in the oscillatory circuit, as we know, charges up the condenser of that circuit to a certain voltage; the greater the current induced in the inductance coil of the wavemeter the higher the voltage to which the condenser will be charged.

432. If, therefore, we place our crystal in series with the telephone across the condenser, as shown in Fig. 67, we shall not in any way interfere with the oscillatory properties of the oscillatory circuit, but we shall get a certain current passing through the crystal and the telephones, the amount of which will depend upon the voltage to which the condenser is charged, and therefore will indicate the amount of current induced in the oscillatory circuit. Moreover, the crystal will rectify this current, so that in effect we shall get a uni-directional current passing through our telephones.

433. The current also will be an intermittent current, the number of interruptions per second being the same as the number of sparks per second in the oscillatory circuit which is being measured (*vide* paragraphs 533 to 536). We shall therefore get **a buzz, or note, in the telephone corresponding exactly to that produced by the spark of the transmitter, and proportional in its loudness to the amount of current induced in the oscillatory circuit of the wavemeter.**

434. It is clear, therefore, that if we vary the adjustable condenser of the wavemeter circuit, and at the same time listen to the sound in the telephones, when this sound is loudest the wavemeter circuit is in tune with the oscillatory circuit, and by noting the position of the condenser thus obtained, and referring this reading to our chart, we find the value of the corresponding wavelength, and therefore the length of the wave emitted by the oscillatory circuit being measured.

Construction of an Adjustable Condenser

435. The construction of an adjustable condenser is illustrated in Figs. 68, 69, and 70. A number of semicircular metal plates A are connected together, and held rigidly parallel to one another and at a sufficient distance apart to allow the second set of metal plates B to pass in between them. Fixed to the upper sides of both the A plates and the B plates are ebonite plates C of the same shape. The second set of metal plates B are held together on a spindle D, which can be rotated by the handle E which is fixed to one end of the spindle.

The fixed plates A form one side of the condenser, and the movable plates B form the other side of the condenser, the dielectric of the ebonite being formed

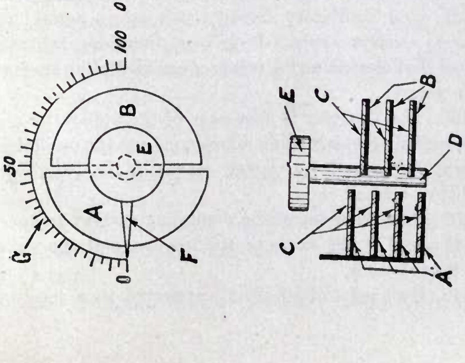


FIG. 68.

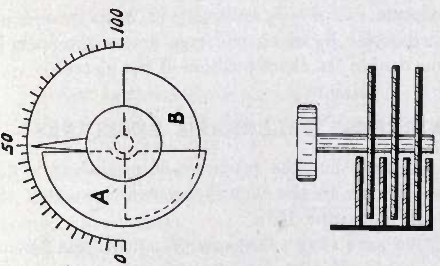


FIG. 69.

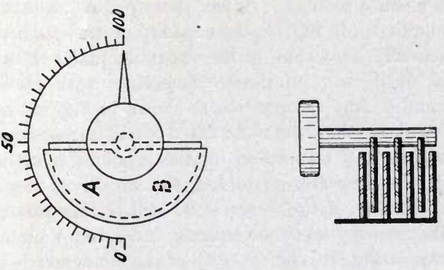


FIG. 70

by the ebonite plates C. When these plates are in the positions shown in Fig. 68, the capacity of the condenser is practically zero, but if the movable plates B are rotated until they interleave themselves with the A plates and occupy the position as shown in Fig. 69, the capacity of the condenser is increased to half its maximum capacity, as half the surface of the A plates is acting through the dielectric on to half the surface of the B plates. Finally, if the B plates be still further rotated until they occupy positions entirely under the A plates, as shown in Fig. 70, the capacity of the condenser is at its maximum. It is only necessary to fix to the moving plates a pointer F, which will pass across the scale G, and thus denote the exact position of the plates.

WIRELESS TELEGRAPH RECEIVERS

436. A wave has the property of producing a disturbance similar to the disturbance which started the wave (*vide* paragraph 156).

437. We have shown that oscillating currents flowing in an open oscillatory circuit, such as an aërial, will produce electric waves. It follows, therefore, from the above, that **electric waves will produce oscillating currents in an aerial.**

438. The Receiver is that part of the apparatus of a Wireless Telegraph Station which converts the oscillating currents produced by electric waves in the aerial into visible or audible signs.

439. **The frequency of the oscillating current produced in the aerial is the same as the frequency of the waves which produce it.**

440. By means of an aerial connected to a receiver,

therefore, we can convert the electric waves which are being radiated from a transmitting station into visible or audible signs, thus enabling us to " read " the message which is being transmitted.

ESSENTIALS OF A RECEIVER

441. We have already explained that an aerial forms an " open " oscillatory circuit and has a natural frequency of its own. We have also shown that an oscillating current will not flow easily in a circuit unless the frequency of that circuit is the same as that of the oscillating current—that is to say, in this case **the aerial circuit must be in tune with the wave which is to be received.**

The first essential of a receiver, therefore, is a variable inductance and a variable condenser, which can be connected in series with the aerial by means of which the latter can be tuned to the desired wave-length.

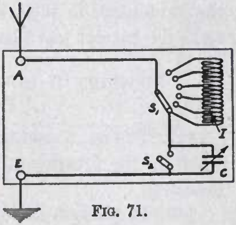


FIG. 71.

442. Fig. 71 illustrates these connections, where A and E are the aerial and earth terminals of the receiver, I is the inductance—more or less of which can be included in the aerial circuit by means of the switch S_1—and C the variable condenser across which is fitted a short-circuiting switch S_2.

443. The inductance I is called the " **Aerial Tuning Inductance,**" and the condenser C the " **Aerial Tuning Condenser.**"

444. We know that by placing a condenser in series

with the aerial we reduce the wave-length of the aerial, and by placing an inductance in series with the aerial we increase the wave-length of the aerial.

445. **If, therefore, the wave-length which it is required to receive is shorter than the natural or "fundamental" wave-length of the aerial** we must cut out all the inductance in the circuit by means of the switch S_1, and we must reduce the value of the adjustable condenser C until the correct wave-length is obtained. The switch S_2 will in this case be open, as shown in the diagram (Fig. 71).

446. **If, on the other hand, the wave-length which it is desired to receive is longer than the fundamental wave-length of the aerial,** in order to bring the wave-length of the aerial into tune we must first short-circuit the condenser C by means of the switch S_2, thus leaving no capacity in series with the aerial, and we must increase the inductance in the circuit by means of the switch S_1 until the correct wave-length is obtained.

Methods of detecting the Oscillating Currents

447. The next essential of the receiver is some device whereby the presence of the oscillating currents can be detected.

448. In paragraph 432 we showed how this could be done, in the case of a wavemeter, by placing across the condenser of the oscillatory circuit a pair of telephones in series with a crystal. **The telephones in series with a crystal constitute a detector.** This method can be adopted in the receiver by placing the detector across the aerial tuning condenser, but it is not an efficient method for the following reason.

449. The aerial tuning condenser forms only a part of the capacity of the whole aerial circuit, so that although the detector may be extremely sensitive, it is not being used to the best advantage.

450. Another method is to **apply the detector across the aerial tuning inductance**, but this method has also the same disadvantage—viz. that we are only applying the detector to a portion of the whole inductance of the aerial circuit.

451. If, however, we are receiving a wave very much longer than the natural wave-length of the aerial, in order to tune up the latter we naturally have to use a large amount of inductance, and if this inductance forms (as it may easily do) the greater part of the inductance of the whole aerial circuit, we may quite efficiently apply the detector across the inductance.

This makes one of the simplest and cheapest forms of wireless telegraph receivers, and is shown diagrammatically in Fig. 72, where A is the aerial, I the variable tuning inductance, E the earth, D the crystal, and T the telephones.

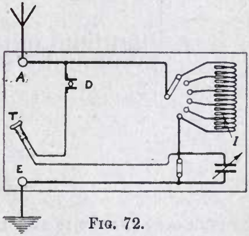


FIG. 72.

452. Most of the amateur stations, more especially those in towns, have very small aerials for obvious reasons, and as they are chiefly used for "picking up" signals from stations using long wave-lengths, this form of receiver is particularly appropriate. With such short aerials even the waves transmitted from ship stations are sufficiently long to necessitate the use of

a comparatively large inductance in series with the aerial, so that the receiver may also be used fairly efficiently for receiving signals from ships.

The Potentiometer

453. Some crystals, for example carborundum, become more sensitive to minute currents when a slight initial voltage is applied across them. **This voltage must**

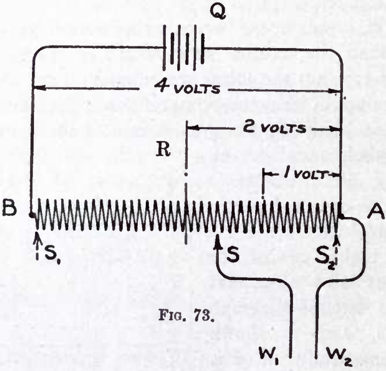


Fig. 73.

be regulated exactly to suit the particular crystal which is being used, and this regulation is accomplished by means of a potentiometer.

454. A potentiometer, shown in Fig. 73, consists of a resistance coil R, connected across a battery Q, and provided with a sliding contact S, by means of which a lead can be connected to any point along the resistance.

455. The resistance of the coil should be kept sufficiently high, so that the current passing through it from the battery is not sufficient to discharge the battery

rapidly. Too high a resistance becomes impracticable, as either the resistance wire with which the coil is wound would have to be so fine that it would easily become broken or cut, or the resistance coil would have to be of such a length that it would not be convenient on account of its size. In practice suitable resistance coils can be wound having a resistance of about 200 ohms, and this connected across a battery of 4 volts will only allow about one-fiftieth of an ampere to pass through it (*vide* paragraph 78), so that a battery consisting of three small dry cells would be sufficient to maintain its voltage for many weeks with continuous working.

456. On referring to diagram (Fig. 73) and assuming that the voltage of the battery is 4 volts, we have a difference of potential between the two ends of the resistance coil, A and B, of 4 volts ; therefore, if we connect a wire W_2 to the end of the resistance coil A, and another wire W_1 to the sliding contact S, and move the latter to the far end of the coil shown in dotted lines and marked S_1, the voltage between the two wires will be 4 volts. If, however, we slide the contact towards the end of the coil marked A, the voltage between the two wires diminishes until the voltage becomes zero, when the slider occupies the position S_2. It is obvious that the voltage across the two wires will be in proportion to the distance the sliding contact is from the point A, and that by moving the slider to any point between the two extreme ends of the resistance we can regulate the voltage between the two wires to any intermediate value between 0 and 4 volts.

457. With most carborundum crystals, the voltage which should be applied across them to bring them to their most sensitive state is somewhere between 1 and 2 volts, so that by applying this potentiometer to our

crystal, we have a simple means of bringing the latter to its most sensitive state.

Method of applying the Potentiometer to the Crystal

458. The method of applying the voltage obtained from the potentiometer to the crystal is not as straightforward as it might at first appear to be.

459. The most obvious way of doing it is shown in Fig. 74, where the two wires from the potentiometer are connected one to either side of the crystal. But it will be immediately seen that **this entirely neutralises the**

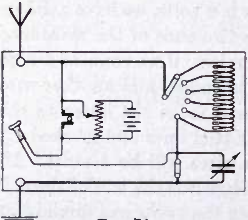


Fig. 74.

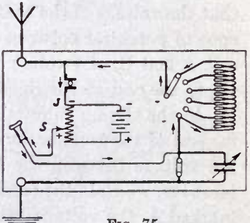


Fig. 75.

value of our crystal as a rectifier, for the oscillating currents, instead of trying to pass through the crystal to the telephones, will pass through the resistance of the potentiometer to the telephones.

460. We must therefore devise some means of applying the voltage to the crystal without making a bye-pass for the oscillating currents induced in the inductance coil.

This can be accomplished by connecting up the circuit, as shown in Fig. 75, where the junction of the battery

and the resistance coil is connected to the earth side of the crystal. One side of the telephone is then connected to the earth terminal, and the other side to the sliding contact of the potentiometer.

461. Assuming that the common junction of the battery, resistance coil, and crystal J is the negative side of the battery, the sliding contact S is the positive, and this positive E.M.F. is conducted to the other side of the crystal through the telephones and through the aerial inductance, as indicated by the arrows.

Thus it will be seen that we have accomplished what we desired, *i.e.* to apply an adjustable voltage across the crystal without forming any short cut for the oscillating currents, which must therefore pass through the crystal and there be rectified before they reach the telephones.

The Two-circuit Receiver

462. As already explained, the single circuit receiver just described is quite efficient for stations that are receiving comparatively long wave-lengths on short aerials, but it would be insensitive for stations which might be required to receive messages on wave-lengths as short as, or shorter than, the fundamental wave-length of the aerial.

463. If we can cause all the energy in our aerial circuit to be transferred to a secondary circuit and apply our detector across the whole of the inductance and capacity of this secondary circuit, it is obvious that the size of the aerial will not limit us as to the value of the wave-length for which such a receiver can be efficiently used.

464. Such a receiver has two distinct oscillatory circuits, both of which must be in tune with the wave-length which it is desired to receive. These two circuits

are called respectively **the primary circuit** and **the secondary circuit.**

465. **The primary circuit**—as in the case of the single circuit receiver—will consist of the aerial, an adjustable inductance, and an adjustable condenser for tuning up the circuit, and a primary coil, by means of which the oscillations can be induced into the secondary circuit, thus transferring the energy from the primary to the secondary circuit (*vide* paragraph 346).

466. **The secondary circuit** will consist of an inductance coil with a variable condenser connected across it, by means of which the wave-length of this circuit can be adjusted so as to be in tune with the primary circuit and at the same time with the wave-length which it is desired to receive.

467. The inductance coil of this secondary circuit must be so placed relatively to the primary coil that the oscillating currents occurring in the latter will induce similar oscillations in the former; that is to say, the axes of the two coils must be in line with one another, and the two coils must be sufficiently close together (*vide* paragraph 407).

468. These circuits are shown diagrammatically in Fig. 76, where the primary oscillatory circuit is formed by A the aerial, I the aerial tuning inductance, C the aerial tuning condenser, P the primary coil, and E the earth.

The secondary oscillatory circuit is formed by S the secondary coil and B the secondary tuning condenser; the common axis of the primary coil and the secondary coil being denoted by the dotted line XY.

469. The method of applying the potentiometer to the crystal in this case is shown in Fig. 77.

470. By applying our detector, as shown in the diagram, across the secondary inductance coil, we are applying it in the most efficient manner possible, since, no matter to what wave-length the secondary

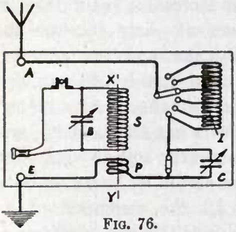


FIG. 76.

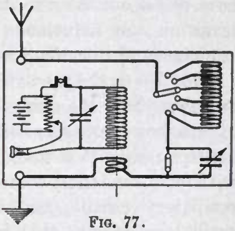


FIG. 77.

circuit is adjusted, the detector will be applied to the whole of the inductance in that circuit.

PROPORTION OF INDUCTANCE AND CAPACITY IN SECONDARY OSCILLATORY CIRCUIT

471. Another point which we have not yet touched upon, affecting the efficiency of the crystal detector, is the proportion of the inductance to the capacity of the oscillatory circuit to which the detector is applied to obtain maximum efficiency. In addition to the fact that it is necessary that the detector be connected across the whole of the inductance, it is found in practice that the greater the inductance of that circuit compared with its capacity, the more efficient will the crystal, as a detector, become.

The reason for this is explained later in paragraph 488, but for the time being we must take it as a fact and develop our receiver accordingly.

472. At first sight it would appear that there is no limit to the amount by which we can increase the inductance of the secondary coil S, so long as we reduce the capacity of the condenser B in proportion. This, however, is not the case, for **by increasing the number of turns on the inductance S we not only increase the inductance of the circuit but also the capacity.**

473. Up to the present we have regarded coils of wire as having only the quality of inductance. As a matter of fact, however, **every coil of wire has self-capacity**, and for this reason it is found that every coil of wire, even without a condenser connected across it, forms an open oscillatory circuit, and has all the essentials of an oscillatory circuit—that is to say, the two qualities of inductance and capacity. This self-capacity then limits the amount of inductance we can use, for in increasing the inductance we cannot avoid increasing also the capacity of the circuit.

474. The most efficient coil that we can design for the secondary circuit of the crystal receiver is therefore one **whose wave-length by itself will be the required value** without the addition of any extra capacity. Our adjustable condenser, however, is necessary in order to enable us to increase the wave-length of the secondary circuit, for a receiver only capable of receiving one length of wave would be very inconvenient; but again we are limited to the extent to which we can vary it by the fact that as we increase the capacity across the inductance, so do we decrease the efficiency of our detector when applied to that circuit (*vide* paragraph 471).

475. In practice it is found that, without materially affecting the efficiency of the detector, we can connect a sufficiently large capacity across the inductance to

increase its wave-length to about three times its original wave-length. If we go beyond this point the reduction in the efficiency of the detector becomes noticeable.

476. We may say, then, that with a two-circuit receiver in which a crystal is used as a detector, the maximum efficiency is obtained when the capacity across the secondary condenser is reduced to zero. Further, we may say that the maximum wave-length to which it can be efficiently tuned will be about three times the value of its minimum wave-length. Thus, if the shortest wave-length which a station is required to receive is 300 metres, the receiver would be designed so that the minimum wave-length to which it can be adjusted will be, 300 metres, and its maximum wave-length will then be about 900 metres.

477. Where a longer range of wave-length than this is required, special arrangements have to be made by which the secondary inductance coil can be changed; thus if a receiver is required to receive wave-lengths of any value between 300 and 1500 metres, it will probably have two secondary inductance coils, one of which will allow the receiver to be tuned up from 300 to 900 metres, and the other from, say, 600 to 1800 metres.

Characteristic Curve of Crystal

478. Up to the present we have considered the action of the crystal to be purely one of rectifying the oscillatory currents induced across it into uni-directional currents.

479. The crystal can be better considered as a conductor offering a certain resistance to current passing through it in one direction, and offering a very much

larger resistance to current trying to pass through it in the other direction.

480. Its value as a sensitive detector, however, depends upon another property. **Even in the direction of conductivity, the crystal does not act in the same way as an ordinary conductor.**

481. With an ordinary conductor the current passing through it increases directly as the voltage applied

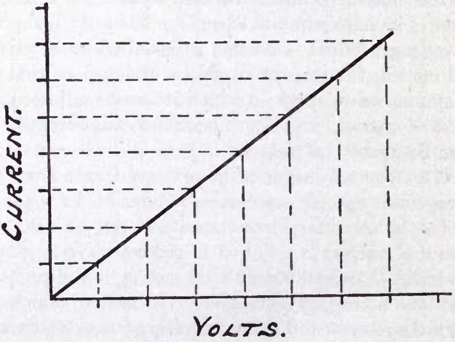


FIG. 78.

across it increases (*vide* paragraph 78). Thus, if we draw a "curve" illustrating the increase in the current which would flow through an ordinary conductor as the voltage across it is increased, this curve would take the form of a straight line, as shown in Fig. 78.

482. **If a curve be drawn illustrating the increase in the current passing through a crystal as the voltage across it is increased, it will take the form shown in Fig. 79.**

483. In this case it will be noticed that when the voltage is increased beyond the point A, the current

passing through it rises very much more rapidly than before in proportion to the increase in voltage across it.

484. This is due to the fact that the effective resistance of the crystal does not remain constant, but starts to decrease when the voltage across it is increased above a certain value.

485. By referring to this curve it will be seen that

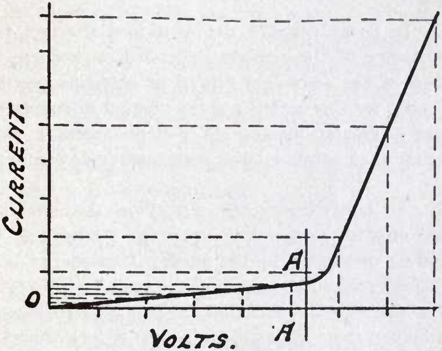


FIG. 79.

between the points O and A a certain increase in the voltage across the crystal produces a very small increase in the current passing through it, and thus through the telephones, whereas **beyond the point A the same increase in the voltage across the crystal produces a larger increase in the current passing through it.**

486. To produce a sound in the telephone it is necessary that the current passing through it be increased, and the strength or loudness of that sound will depend upon the amount by which the current is increased.

487. It is obvious, therefore, that the voltage produced across the secondary coil of the jigger by the oscillating currents will cause a greater increase in the current passing through the crystal and telephones if it be applied after the point A is reached. It is for this reason that a potentiometer is necessary in order to bring the initial voltage across the crystal up to the point A.

488. In paragraph 471 we mentioned the fact that the efficiency of the receiver depended on keeping the capacity of the secondary circuit as small as possible. The reason for this is that **a given amount of energy will produce a greater increase in voltage across a small condenser than across a large condenser** (*vide* paragraph 272).

Now in our receiver the energy in the circuit is a fixed quantity, depending upon the strength of the oscillations produced in the aerial; this energy is in turn transferred to the secondary circuit.

It is therefore obvious that the only way to increase the voltage across the condenser is to reduce the value of that condenser.

489. In so reducing it we reduce also the wave-length of that circuit, and as it is necessary to keep this in tune with the wave-length which is being received, we must counterbalance the effect of reducing the capacity by increasing the inductance of the circuit. The extent to which we can do this, as already explained, is limited by the fact that every coil of wire has self-capacity, and as we increase the coil to get a greater inductance, so, at the same time, we increase its capacity.

490. The rate at which we increase this self-capacity, however, can be controlled, to a large extent, by the

design of the coil—that is to say, by its diameter, its length, and the size of the wire with which it is wound.

491. A question which will probably arise in the minds of those studying this explanation will be that, in describing the receiver, we said that the crystal was placed across the inductance, whereas in explaining the reason for keeping this inductance high, in proportion to the capacity, we take the point of view that we wished to increase the voltage across the condenser. This is only because it is easier to understand how the voltage must necessarily increase across the condenser if the value of that condenser is decreased, and, since in an oscillatory circuit the condenser is connected across the inductance, it follows that the voltage across the inductance is likewise increased.

THE TELEPHONE RECEIVER

492. So far we have not touched upon the construction of the telephone receivers.

The function of the telephone receivers (usually called "telephones" for short) is to convert electric currents into an audible sound.

It is of course of as much importance for this part of the apparatus to be efficient as any other, and in order to be efficient it must be made suitable for the circuit to which it is applied.

493. A telephone receiver consists essentially of an electro-magnet and a diaphragm.

The diaphragm is a circular piece of very thin sheet iron, supported all round the edge by the outer case, or shell, of the "ear-piece," as close to the face of the magnets as possible without actually touching.

494. Fig. 80 shows diagrammatically a section of a telephone ear-piece where A is the iron core of the electro-magnet, B the coils of the electro-magnet, C the case, or shell, and D the diaphragm.

495. Unlike an ordinary electro-magnet, the iron core of the telephone receiver is to a certain extent permanently magnetised.

496. It is evident, then, that the diaphragm will

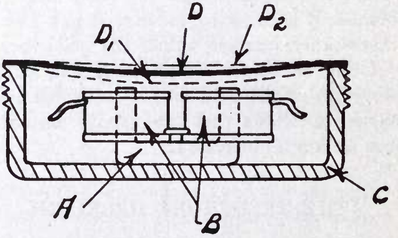


FIG. 80.

normally be strained slightly towards the magnet, as shown by the full line D, in Fig. 80.

As already mentioned, it is supported by the shell of the ear-piece all round its edge, but, being thin and springy, it will bulge in the middle towards the magnet.

497. The action of the telephone receiver is as follows: If a current is sent through the coils in such a direction that the lines of force set up by it assist those of the permanent magnet, the strength of the magnet will be increased, and the diaphragm will be attracted still closer to the magnet, thus taking the position shown by the dotted line D_1.

498. If, on the other hand, a current is sent through

the coil in the opposite direction, thus setting up lines of force **opposing those of the permanent magnet**, the strength of the magnet will be decreased and the diaphragm will be allowed to spring farther away from the pole and take up the position shown by the dotted line D_2, owing to the fact that it has already been displaced out of its normal position due to the normal pull of the permanent magnet.

499. Owing to the form of the diaphragm, it acts in just the same way as the head of a drum, and will produce a big sound with a comparatively small displacement of its centre.

Just as the noise produced by a drum will depend upon how hard it is hit by the drumstick, so will the noise produced by the diaphragm depend upon the amount of increase or decrease in the magnetisation of the magnet.

High Resistance Telephones

500. It is obvious that the increase or decrease in the magnetism of the magnet will depend upon the magnetisation force or "magneto-motive force" which is applied to it.

The magneto-motive force depends upon two things: (1) the number of turns of wire which are encircling the magnet, and (2) the amount of current passing through them (*vide* paragraph 96).

501. For a given size of magnet we have only a definite space into which to get our turns of wire, so that the only way of increasing the number of turns we can wind on the magnet is to decrease the size of the wire. The thinner the wire the greater the number of turns which we can get into the space at our disposal.

502. Unfortunately, however, as we reduce the size of the wire, so do we increase the resistance per turn of that wire, and therefore decrease the amount of current which would pass through it for a given voltage. Therefore, **unless the current at our disposal is already limited by some external resistances**, we shall not gain anything by increasing the number of turns if at the same time we increase the resistance of the coil in proportion.

503. If, however, the telephone is in a circuit in which there is already a high resistance, then the increase in the resistance of the coil will not have so great an effect on the total resistance of the circuit, and therefore on the current which is passing through that circuit.

504. For an example, let us suppose that a coil wound with 10 turns of a certain size wire will have a resistance of 1 ohm, and let us suppose that the external resistance of the circuit in which the coil is connected is 99 ohms. The total resistance of the circuit is then 100 ohms. If our voltage across this circuit is 1 volt, then it follows that our current through this resistance will be a one-hundredth part of an ampere, and consequently—

$$\text{Magneto-motive force} = \tfrac{1}{100} \times 10 \text{ turns} = \tfrac{1}{10}.$$

505. Now let us wind the same coil with wire $\frac{1}{10}$th the former cross-sectional area. It follows that we shall get 10 times the number of turns—that is to say, we shall get 100 turns of wire on to the coil, but our resistance per turn will be increased ten times. The resistance per turn in the first coil was $\frac{1}{10}$th of an ohm, so that our resistance per turn will now be 1 ohm; therefore the resistance of the coil will be 100 ohms.

506. Adding this to our external resistance we get a total resistance in the circuit of 199 ohms. Now

for the same voltage, *i.e.* 1 volt across this circuit, we shall get $\frac{1}{199}$th of an ampere, and therefore in this case—

$$\text{Magneto-motive force} = \frac{1}{199} \times 100 = \text{approx. } \tfrac{1}{2}.$$

507. It is obvious, therefore, that in this case we have increased our magneto-motive force nearly five times by winding the coils with a finer-sized wire.

508. On examining the diagrams of connections of our wireless telegraph receiver, it will be seen that **any current passing through the telephones will have to pass through the crystal.**

509. The resistance of our crystal at its most sensitive point is of the order of 10,000 ohms. It will therefore be obviously inefficient to wind the telephone receiver with such a sized wire that its resistance is only, say, 200 ohms, if a finer wire is available.

510. In practice special telephones are made suitable for circuits with such external resistances. These telephones are wound with the very finest wire which it is possible to manufacture, in order to get the greatest possible number of turns on to the limited space of the bobbins.

511. Such telephones are called High Resistance Telephones, and have a resistance of approximately 3500 ohms per ear-piece, and two ear-pieces can be used, connected in series, thus making a total resistance of a pair of telephones about 7000 ohms.

512. The point which must be clearly understood is that **the object of using high resistance telephones is not because they have a high resistance, but because they are wound with a very much larger number of turns than the low resistance telephones**, and therefore, owing to

the high external resistance of the circuit, the magneto-motive force is increased to a greater extent than it is decreased by the increase of resistance of that circuit.

Rectifying Properties of Carborundum

513. In paragraph 485 we explained why it is necessary to adjust the initial voltage across the carborundum crystal to a certain value in order that a given increase in voltage will cause the greatest possible increase in the current passing through it. We have not, however, explained why it is necessary to adjust the initial voltage across the crystal to the exact point where the effective resistance of the crystal commences to decrease rapidly.

514. Referring again to the characteristic curve of a carborundum crystal shown in Fig. 79, although it is obvious that the crystal will be more sensitive when the point A is reached, it is not quite so obvious why it is necessary to adjust the initial voltage across the crystal exactly to the point A, and not to any point beyond it, such as the point B shown in Fig. 81.

515. As can be seen from this curve, a given increase in voltage will cause practically the same increase in current passing through the crystal whether this increase be applied at the point B or the point A, but we must remember that the extra voltage provided by the oscillatory current in the secondary of the jigger is an alternating current voltage, that is to say, a voltage varying from a positive value at one instant to a negative value at the next instant.

516. Since the initial voltage applied across the crystal is a direct current voltage obtained from the

potentiometer, it follows that the alternating current voltage will at one instant be assisting the direct current voltage, and at the next instant opposing it.

To facilitate explanation, let us put these voltages into figures.

517. Let us suppose that the initial voltage across the crystal to bring it up to the point A is 2 volts, and the voltage required to bring it up to the point B is $2\frac{1}{4}$ volts, these voltages being positive volts.

518. Let us also suppose that the value of the alternating voltage provided by the oscillating current varies from **minus** $\frac{1}{2}$ a volt to **plus** $\frac{1}{2}$ a volt; it is obvious, then, that during the time that the oscillations are being received the resulting voltage across the crystal, **if the initial voltage be adjusted to the point A**, will vary from $1\frac{1}{2}$ volts to $2\frac{1}{2}$ volts. Similarly, **if the initial voltage across the crystal be adjusted to the point B**, the resulting voltage will vary from $1\frac{3}{4}$ volts to $2\frac{3}{4}$ volts.

519. Now let us draw two separate curves, shown in Figs. 82 and 83, showing the result of this variation in voltage on **the current passing through our telephones**, taking our figures from the curve shown in Fig. 81.

The curve in Fig. 82 shows the resulting current in the telephones when the initial voltage of the crystal is adjusted to point A.

520. At this point the value of the current passing through the crystal and telephones before any oscillations are produced in the secondary circuit is 1, therefore we may draw a heavy line DD, representing **the normal value of the current.**

521. When the negative part of the first oscillation is applied across the crystal, the result, as already explained, is to reduce the voltage to $1\frac{1}{2}$ volts, thus the current

passing through the telephones will be reduced, but, as will be seen by referring to Fig. 81, owing to its being on

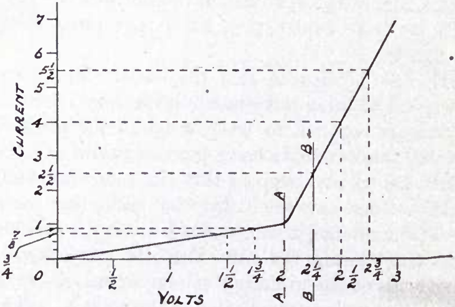


FIG. 81.

the flat part of the curve, the reduction in the amount of current passing through the telephones is extremely

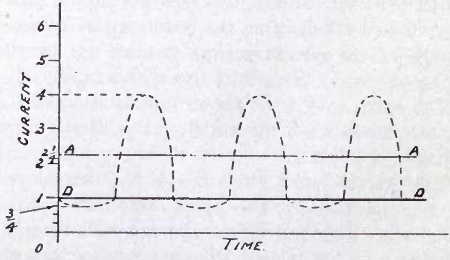


FIG. 82.

small; by reading from the curve we find it is reduced to the value of $\frac{3}{4}$.

Therefore the curve representing the actual current

passing through the crystal and telephones when the negative part of the first oscillation is applied, will dip just below the line DD.

522. The next half of the oscillation is positive, and therefore has the result of increasing the voltage across the crystal to $2\frac{1}{2}$ volts.

By referring again to Fig. 81, it will be seen that the effect on the value of the current is to increase it to 4.

We may therefore continue our current curve in

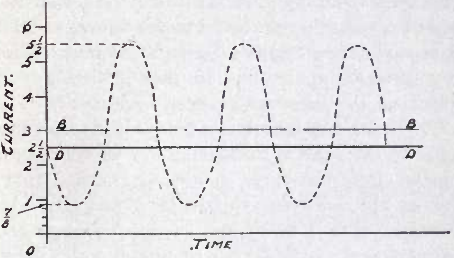


FIG. 83.

Fig. 82, which will now show the current rising to the value 4 above the normal line DD.

523. A similar cycle will take place for each oscillation, **with the result that we get a series of high peaks above the normal current line, and a series of very shallow dips below this line.**

524. These oscillations are taking place at the rate of perhaps millions per second, according to the length of wave which is being received.

If the wave-length received is 100 feet, the number of oscillations per second will be 10 millions per second (*vide* paragraphs 167 and 174).

525. These variations are infinitely too rapid for the diaphragm of the telephone to follow, and **it will therefore be deflected to an extent corresponding to the average value of the current passing through its coils.**

526. Referring to Fig. 82 the average current passing through the telephones when the oscillating voltage is applied across the crystal is shown by the dotted line AA, drawn approximately half-way between the highest and lowest point on the curve. This value is somewhere about $2\frac{1}{4}$, and the sound produced in the telephones will be proportional to the difference between the normal current passing through the telephones and the increased current due to the oscillating voltage applied, *i.e.* the difference between 1 and $2\frac{1}{4}$.

527. Now let us see what takes place if we adjust the crystal to the point B; obtaining our values of current as before from the curve in Fig. 81, we find that the result of the oscillating voltage is to vary the value of the current from $\frac{7}{8}$ to $5\frac{1}{2}$, and we may therefore draw a new curve as shown in Fig. 83, representing this variation in the value of the current.

528. Again, these variations in current are too rapid for the diaphragm of the telephone to follow, so that it will again be deflected to an extent corresponding to the average value of this current.

529. The average value of this current will be about 3, so that we may draw a dotted line BB, representing the average value of the current passing through the telephones when the oscillating voltage is applied across the crystal.

530. But we have already increased the normal value of the current passing through the telephones to the value of $2\frac{1}{2}$, as shown by the line DD, Fig. 83, this being

the current which will pass through the crystal and telephones when the initial voltage of $2\frac{1}{4}$ volts is applied to bring it up to the point B, Fig. 81.

531. **The strength of the sound produced in the telephones will be proportional,** not to the total current passing through the telephones, but **to the difference between the current passing through them when no oscillations are being received and the average current passing through them when the oscillations are being received.**

532. When the crystal was adjusted to the point A, this difference in current was the difference between 1 and $2\frac{1}{4}$, so that the strength of the sound was proportional to $1\frac{1}{4}$; but when the crystal was adjusted to the point B, the strength of the sound was proportional tc the difference between $2\frac{1}{2}$ and 3, which is only $\frac{1}{2}$.

Relation between the Spark Frequency of the Transmitter and Sound produced in the Telephones of Receiver

533. In paragraph 433, describing the wavemeter (which is in reality a simple form of tuned receiver), we said that the current produced in the telephone receiver would be an intermittent current, and the number of interruptions per second would be the same as the number of sparks per second in the oscillatory circuit which is being measured.

The explanation of this is easy to follow if the foregoing paragraphs are thoroughly understood.

It is obvious that the average current passing through the telephone from any group of oscillations may be regarded as a direct current flowing so long as the oscillations are maintained.

534. If, then, the transmitting station were sending out a stream of continuous waves (*vide* paragraph 213), so long as the manipulating key were kept depressed we should get a continuous current flowing through the receiver, without interruption.

As a matter of fact, however, when we depress the manipulating key we get a succession of short groups of damped waves, one group each time the condenser is charged by the induction coil and discharged through the spark gap.

535. The uni-directional current, therefore, produced in the telephone of the receiver will only be maintained for the time that the group of waves lasts, with the result that the diaphragm of the telephone is deflected for an instant only, and returns to its normal position until another group of waves is received; **thus a single click will be produced by each group of oscillations.**

536. As each spark in the transmitter produces a group of waves, so does each group of waves in the receiver produce a click in the telephones. Thus the sound produced in the telephones, or, in other words, the frequency of the clicks in the telephones, will correspond with the spark frequency of the transmitter.

To tune a Receiver

537. We will suppose that our receiver is of the two-circuit type—that is to say, that it has a primary circuit and a secondary circuit, both of which must be in tune with the wave-length it is desired to receive. **The only means we have of telling whether the receiver is in tune is by the strength of the signals in the telephones.** If either circuit of the receiver is out of tune, the signals are weakened, so that provided we have a

variable inductance or condenser in each circuit, and provided we can hear at least weak signals in the telephones, it is a simple matter to tune up the receiver by listening to the strength of the signals and adjusting first one circuit and then the other circuit, until the sound is at its loudest.

538. If, however, we are so much out of tune to begin with that the signals are inaudible, the difficulty of tuning up is increased enormously.

539. In the case of a single-circuit receiver the difficulty is not so great, for we have only one circuit to adjust, and therefore we can vary it slowly from its maximum wave-length to its minimum wave-length, and consequently we are bound to pass the point where the receiver is in tune with, and therefore will respond to, the signals.

540. In the case of a two-circuit receiver, however, if signals are inaudible to begin with, we have no means of telling which circuit is out of tune or when the two circuits are in tune with each other.

541. If we know the wave-length of the signals we wish to receive, and we have an instrument close to our receiver which can be made to emit a similar wave-length, the process of tuning up becomes quite simple.

Such an instrument is called a tuning buzzer.

542. Since our detector and telephones are actuated by the secondary circuit of the receiver, we **should first** cause the tuning buzzer to induce waves into the secondary circuit only, and we should then **adjust this circuit until the buzzer signals in the telephones are at their loudest.**

Having accomplished this, we **should next** move the tuning buzzer to a point remote from the secondary

circuit, but close to some part of the primary or aerial circuit, so that no oscillations can be induced from it directly into the secondary circuit, but only through the primary circuit.

543. Now if the primary circuit is very much out of tune with the wave-length emitted by the tuning buzzer, it will not respond to the oscillations, and therefore no oscillations will be induced in the secondary circuit, but if we vary the wave-length of the primary circuit, we shall reach a point when it is in tune with the wave emitted by the tuning buzzer. Oscillations will then be induced in the primary circuit, which will in turn induce oscillations in the secondary circuit, as the secondary circuit has already been tuned to the same wave-length. Thus when by varying the adjustment of the primary circuit **we reach a point when the signals in the telephones are again at their loudest**, we know that we have reached the point when the primary circuit is in tune with the tuning buzzer, and therefore both circuits are in tune with the wave-length emitted by the tuning buzzer.

THE TUNING BUZZER

544. The essentials of a tuning buzzer are, therefore, (1) that it can be caused to emit feeble oscillations, and (2) that the frequency of these oscillations can be adjusted to any predetermined value.

545. To accomplish these desiderata, the tuning buzzer has two circuits: **firstly, an oscillatory circuit**, consisting of an inductance coil with an adjustable condenser, and, **secondly, a generating circuit**, by which the oscillatory circuit is excited.

546. The construction of the oscillatory circuit of a tuning buzzer is identical with that of the wavemeter, which was described in paragraph 417. It consists of a fixed inductance coil connected in series with an adjustable condenser, the latter being provided with a scale and pointer by means of which the value of the wave-length to which that circuit is adjusted is indicated.

547. There are several ways in which this circuit can be excited. We can, of course, charge up the condenser by means of an induction coil and discharge it through a spark gap in the oscillatory circuit, as

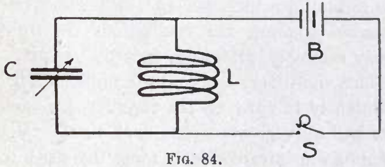


FIG. 84.

described in paragraph 319; but this would be an expensive method and, moreover, **would produce very much stronger signals than are necessary.**

548. The method most commonly used is shown diagrammatically in its simplest form in Fig. 84, where L is the inductance coil, C the condenser forming the oscillatory circuit, and where B is a battery connected across the inductance coil through the contact S. If the contact S is depressed, thus completing the circuit from the battery through the inductance coil, a continuous current will flow through this coil. If this circuit is broken by releasing the contact the current will be instantaneously interrupted.

549. As already described in paragraph 62, the property of inductance is similar to the mechanical property of momentum, and therefore, **when the current is suddenly interrupted**, the energy due to its momentum is liberated, and is expended in the oscillatory circuit of which this inductance forms a part. The result is practically to give this circuit a kick, causing it to oscillate to its own natural frequency; thus every time the battery circuit is broken we produce a group of oscillations in the oscillatory circuit corresponding to the wave-length to which that circuit is adjusted.

550. If a battery of only two or three volts be used and the inductance included in the battery circuit be a reasonable amount, the oscillations set up will be sufficiently strong to affect our receiver circuit.

551. This, however, is not quite sufficient to enable us conveniently to tune up the receiver, for each group of waves will only give a single click in the telephones. **Some automatic arrangement must be used to make and break the circuit rapidly in order to produce a continuous buzz or note in the telephones,** it being very much easier to distinguish when a buzz or note reaches its maximum strength than if only a number of single clicks were audible.

552. One method by which this rapid making and breaking of the circuit can be accomplished is shown diagrammatically in Fig. 85, where the battery circuit B, through the inductance L, is made through a pair of contacts S, S, one of which is mechanically connected to the armature A of an ordinary electric buzzer D, so that when this armature vibrates it causes the extra pair of contacts S, S alternately to make and break the battery circuit through the inductance L.

553. In this case **two batteries are required,** one for working the buzzer and the other for the oscillatory circuit.

554. There is no reason, however, why the ordinary single contact buzzer cannot be used for exciting an oscillatory circuit, for by connecting it in such a way that the current passing through the coils of the buzzer is made to pass also through the inductance of the oscillatory circuit, as shown in Fig. 86, we have practically the same conditions as before. Energy will be stored up in the inductance L, while the current is passing

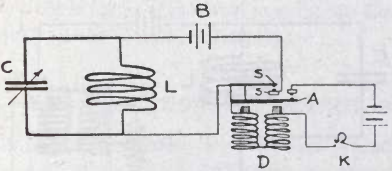


FIG. 85.

through it, and will be liberated as soon as it is interrupted at the contacts S, the energy thus liberated giving the oscillatory circuit a kick, and thus causing it to oscillate to its own natural frequency.

555. In this case, however, when the contacts S are broken, we not only liberate the energy stored up in the inductance L, **but we also liberate the energy which is stored up in the inductive coils of the buzzer itself.**

The inductance of these coils is many times greater than the inductance in the oscillatory circuit, and therefore a very much larger amount of energy will be liberated at this point when the circuit is interrupted.

556. If no path is provided in which this energy can

dissipate itself, it will form a small arc at the contacts S, and dissipate itself gradually in this manner.

557. Unfortunately, this arc will also form a path for the energy stored up in the inductance L, with the result that the energy will be dissipated in the same way without charging up the condenser; so that under these conditions the oscillatory circuit would not be excited.

558. If, however, we connect a non-inductive resistance, as shown by R, Fig. 86, across the coils of the

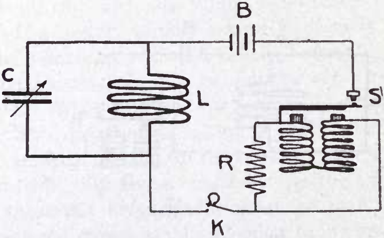


Fig. 86.

buzzer, **the energy liberated from the buzzer coils will expend itself in the circuit formed by the coils of the buzzer and the resistance coil R,** instead of forming an arc at the contact S. **But the energy liberated from the inductance L will not have this circuit in which to expend itself,** for the circuit is interrupted at the contact S, and will therefore have to expend itself in charging up the condenser C.

559. The connections shown in the figure are those usually adopted in an ordinary tuning buzzer, and it is obvious that the instrument can be used either to buzz

a calibrated closed oscillatory circuit, and so make it emit waves of any desired length for the purpose of testing receivers, etc., or it can be used to buzz any other oscillatory circuit in order that the wave-length of that circuit may be measured by means of a wavemeter.

560. We have now explained briefly the principles of the design and application of crystal receivers. There are, however, many other forms of receiver, some of which make use of phenomena entirely different from those already explained.

The purpose of this book will be served by describing only two other forms of receiver, namely, **the Electrolytic Detector** and **the Magnetic Detector.**

THE ELECTROLYTIC DETECTOR

561. In the Electrolytic Detector, use is made of the depolarising effect which oscillatory currents produce on a polarised electrolytic cell.

As some readers may be unacquainted with simple chemical theory, we think it advisable first of all to give a short account of the composition of water.

Composition of Water

562. Water is described chemically by the formula H_2O, which means that it consists of two parts by volume of the gas hydrogen (H), and one part of the gas oxygen (O), in chemical combination with one another.

563. Most readers will have noticed that if a gas-jet is burned in a small room for any length of time, a considerable amount of water is condensed on the window panes. This is really due to the fact that the

oxygen in the surrounding atmosphere combines chemically with the hydrogen in the coal gas, and forms water. This chemical action produces energy in the form of heat which is apparent from the very high temperature of the gas flame.

On account of this high temperature, the water which results is produced in the form of steam, and is therefore invisible until it has had time to condense on to some body which will conduct the heat away from it.

564. Hydrogen and oxygen will only combine when brought to a high temperature, so that if they be simply mixed together at a normal temperature no chemical action will take place, but as soon as a spark or flame is applied to the mixture the gases immediately surrounding the spark are brought to a high temperature, with the result that chemical action is started. The heat produced by this action is more than sufficient to keep the process of combustion going, so that even if the spark or flame which started the action be removed, the gases continue to combine until one or the other of them is exhausted.

565. Hydrogen and oxygen, like every other substance, consist of a very large number of minute units to which scientists have given the general name of "molecules." Every molecule is still further subdivided into units, known as "atoms," each molecule consisting of a definite number of atoms. The molecule of oxygen, for instance, contains two atoms of oxygen; the molecule of hydrogen contains two atoms of hydrogen; the molecule of water, however, contains three atoms, namely, two of hydrogen and one of oxygen.

The minuteness of a molecule can be gauged from the fact that the smallest particle of water which can be

seen under the most powerful microscope is made up of many millions of molecules.

566. Figs. 87 and 88, which show a simple graphical illustration of the molecular theory, will enable the reader to imagine more easily the difference between a mixture and a combination. In these illustrations we have represented molecules by a number of irregular outlines, and atoms by small spheres contained inside the molecule. For the purpose of distinguishing them we have represented the hydrogen atoms as white dots, thus, o ; and the oxygen atoms as black dots, thus,

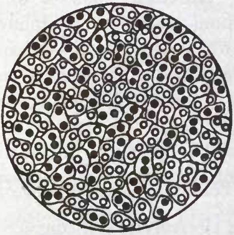


Fig. 87.

Fig. 88.

567. Fig. 87 represents a number of hydrogen and oxygen molecules mixed together, and as no chemical action is yet supposed to have taken place, the hydrogen and oxygen molecules still retain their individuality. If this mixture be ignited the result of the chemical combination of the hydrogen and oxygen is shown in Fig. 88, where the hydrogen and oxygen no longer exist as separate molecules, but have combined in the proportion of two molecules of hydrogen to one of oxygen, and form entirely new molecules, namely, molecules of water.

This brief description will perhaps assist the reader to understand the action of an electrolytic cell.

Electrolytic Cell

568. An Electrolytic Cell is an apparatus for splitting up the molecules of water, or other compounds, into their original elements. It is found that when a current of electricity is made to pass through a conducting solution of water, the water is decomposed, that is to say, the molecule of water is split up into the three atoms, two of which are hydrogen and one oxygen.

569. An electrolytic cell, therefore, consists of a vessel usually of glass, containing a solution of sulphuric or nitric acid in water, into which are dipped two conducting rods called the electrodes. These rods are usually made of platinum or some other non-corrosive metal.

570. The object of the acid is to make the water conducting, pure water being practically a non-conductor of electricity.

571. Fig. 89 shows such an electrolytic cell connected to a battery as the source of E.M.F.

The electrode to which the positive side of the battery is connected is called the *anode*, and the electrode to which the negative side of the battery is connected is called the *cathode*.

572. The current flowing through the electrolytic cell from the battery decomposes the water at a rate in proportion to the strength of the current flowing through the cell. The gases thus formed are not liberated evenly throughout the liquid, but *collect at the electrodes* and then rise to the surface in bubbles, the oxygen collecting at the anode and the hydrogen at the cathode.

As water consists of two atoms of hydrogen and one of oxygen, twice as much gas will collect at the cathode as at the anode.

573. The amount of water decomposed, and therefore *the amount of gas given off at the electrodes, is proportional to the current passing through the liquid,* it follows, therefore, that if the resistance of the electrolytic cell, as well as the resistance of the outside circuit supplying the E.M.F. necessary to pass the current

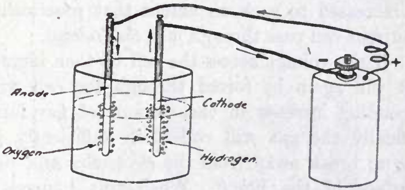


FIG. 89.

through the cell, remained constant, the amount of gas given off *would be proportional to the voltage* applied across the cell.

574. This condition, however, is not obtained in practice, for when only a small voltage is applied across the cell the gas is not produced in sufficient quantity to break away from the electrodes, instead it sticks to the surface of the platinum in the form of tiny bubbles, thus reducing the area of contact between the electrode and liquid. This has the result of very considerably increasing the resistance of the electrolytic cell. This effect is known as *polarisation,* and when the gas is removed either by mechanical, chemical or other means, the effect is known as *de-polarisation.*

575. In the case of electrodes being of a considerable size, that is to say, having a large surface in contact with the liquid, the increase in the resistance of the cell is not so marked, and, moreover, a stronger mechanical or chemical action is required to de-polarise it than if the contact surface between the electrode and liquid is very small.

576. Now, provided the electrode has a sufficiently small area of contact with the liquid to begin with, this polarising action continues until the resistance of the cell is increased to such an extent that practically no more current can pass through it *at that voltage.*

577. If the voltage across the cell be then increased, current will again be forced through the cell with a corresponding increase in the amount of gas formed, until finally the gas will collect in sufficiently large bubbles to break away from the electrodes and rise to the surface of the liquid. When this happens the liquid again comes into contact with the electrode, with the result that the resistance of the cell drops; this effect in turn allows a larger current to flow through the cell, *and the gas then continues to be liberated in sufficient volumes to bubble freely away from the electrode until the current is cut off.*

The electrolytic cell is most sensitive to the action of the high frequency currents when it is in the first stage of the process described above, that is, *when the initial voltage applied across the cell is only sufficient to form a cushion of gas round the electrode.* If at this stage a high-frequency voltage is applied to the cell, the cushion of gas is apparently broken up and the liquid again comes into contact with the electrode, causing a sharp drop in the resistance of the cell. Thus

we may say that the action of high frequency oscillating currents on a polarised electrolytic cell is to de-polarise the cell.

578. Figs. 90 and 91 show how the electrolytic detector can be connected up to the receiver circuits. If these diagrams be compared with Figs. 75 and 77, which show the method of connecting a crystal detector of the receiver circuits, it will be noticed that identically the same circuits are used in both cases.

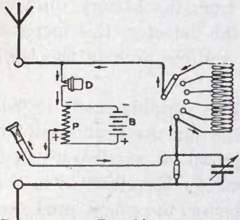


Fig. 90.

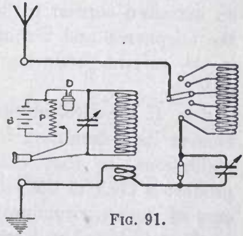


Fig. 91.

579. The action to the two detectors, however, is fundamentally different, and it is essential that this difference be thoroughly understood.

In paragraphs 429-433 we explained that the function of a crystal is to rectify oscillating currents received, thus converting them into uni-directional currents which can be made to produce audible sounds in the ear-piece of a telephone (*vide* also paragraph 525)

580. Now let us see what happens in the case of an electrolytic detector; by following the diagram in Fig. 90 it will be seen that the initial voltage across the detector D is provided from the battery B and potentiometer P. By means of the potentiometer the

voltage is adjusted to such a value that the resistance of the cell is at its highest (*vide* paragraphs 576 and 577).

Since the telephones T are in series with the detector, the current passing through the telephones will then be practically zero. In any case what little current there is will be of constant value, and will therefore produce no sound in the telephones (*vide* paragraph 486). As soon as a train of high frequency oscillations are induced in the jigger secondary, the electrolytic detector becomes de-polarised, and its resistance therefore drops, allowing an increased current to flow from the battery through the telephones and through the detector, this increase in the current producing an audible click in the telephones.

581. If the electrolytic cell is suitably made it will recover its polarisation in time for the next group of oscillations, so that each group of oscillations will produce a click in the telephones; therefore, as in the case of the carborundum detector, the sound produced in the telephones will correspond exactly to the spark frequency of the transmitter.

582. In order to produce an electrolytic detector which will in the first place be sensitive to very feeble oscillations, and also which will recover its polarisation rapidly enough for the highest practicable spark frequency, the active electrode which is the anode must be of extremely small dimensions. To this end the anode usually consists of an extremely fine platinum wire fused into a glass holder, a magnified sketch of which is shown in Fig. 92. The end of the platinum wire projects only a fraction of a millimetre beyond the glass; thus no matter how much the glass is immersed in the electrolyte, only that part of the platinum wire

which projects beyond the glass will come into contact with the liquid.

583. So long as the anode is small the size of the

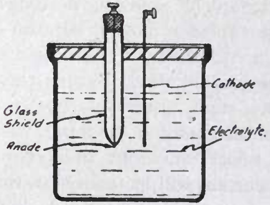


FIG. 92.

cathode is of no importance, and for this reason usually consists of a comparatively thick platinum wire thoroughly immersed in the liquid at any convenient distance.

THE MAGNETIC DETECTOR

584. In the Magnetic Detector use is made of that property in iron known as **magnetic hysteresis.**

MAGNETIC HYSTERESIS

If a piece of iron be brought near the pole of a magnet, that part which is nearest the magnet becomes magnetised to an opposite polarity by magnetic induction (see paragraph 83).

585. If it is then removed from this magnetising force, it will still retain a certain amount of the magnetism induced into it, **by reason of its " retentivity.**

586. In the case of soft iron this residual magnetism is extremely unstable, and a very small mechanical shock or twist is quite sufficient to destroy it.

In other words, the magnetism in the iron does not

follow exactly any change in the magnetising force, but lags a little behind it This lagging behind is called "Hysteresis."

587. In paragraph 98, under the heading of "Magnetic Induction," we explained how an electric current could be induced in a coil of wire by causing a change in the strength of the magnetic field passing through the coil.

If, then, we wind a coil of wire round an iron core, and **after magnetising the latter**, we subject it to a mechanical shock, sufficient to destroy its residual magnetism, **a current will be induced in the coil of wire.** Moreover, if we connect a pair of telephones across the coil, thus causing the current induced into it to pass through the telephones, we shall get a click in the telephones when the iron is de-magnetised.

Having de-magnetised the iron it must be re-magnetised before a similar mechanical shock will produce another current impulse in the coil.

588. It is obvious that the intensity of the current induced in the coil of wire will depend on the difference between the amount of magnetism in the iron before and after it is subjected to the de-magnetising influence of the mechanical shock.

589. A very feeble shock will only partially de-magnetise the iron, with the result that a feeble sound is produced in the telephones; but if the shock is sufficiently strong to destroy all the magnetism in the iron, we shall get a maximum sound in the telephones, and any further increase in the strength of the shock cannot further increase the sound produced in the telephones.

590. We have, however, a means of still further increasing the strength of the current induced in the coil. Owing to its hysteresis the iron will retain its residual

magnetism, not only when the magnetising force has been removed, but also when it has been reversed, provided that this reversed magnetising force is not too powerful.

In this case the effect of our subjecting the iron to a mechanical shock is not merely to destroy its residual magnetism, but to allow it to become magnetised in the opposite direction by the influence of the reversed magnetising force.

The intensity of the current induced in the coils will then be proportional to the amount of residual magnetism in the iron which is destroyed, plus the amount by which it is magnetised in the opposite direction.

591. It was discovered **that if a high frequency oscillating current were passed through a coil of wire round a piece of iron, it produced an effect on the iron similar to that produced by a mechanical shock.**

592. Let us now see how these principles are applied in the magnetic detector.

An endless band B, Fig. 93, consisting of a number of fine strands of iron wire, is passed over two pulleys P, P_1, one of which is kept slowly rotating by means of clockwork, thus keeping the band continuously moving in the direction indicated by the arrow. The band is made to pass through a small glass tube C, around which is wound a single layer of insulated copper wire, the two ends of which are connected, one to the aerial and the other to the earth.

A second coil of wire D, consisting of a very much larger number of turns of wire, is also wound around the glass tube, and across this coil is connected a pair of telephones T. A single horse-shoe magnet M is placed in a position similar to that shown in Fig. 93, with one

of its poles (in this case the north pole) close to the band a short distance away from the windings, the other pole a little distance away from the band near the middle of the windings.

593. Let us now watch the progress of a particular portion of the band while it travels from the point X to the point Y.

It first of all approaches the north pole of the magnet, and thereby becomes magnetised as a south pole by

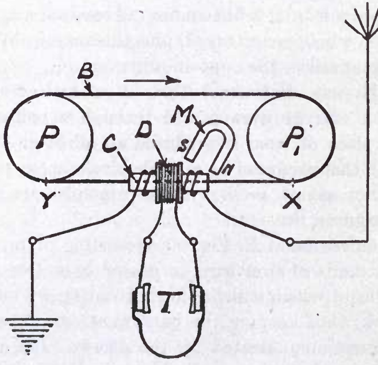


FIG. 93.

magnetic induction. As it proceeds farther on its course it gets farther and farther away from the magnetising influence of the north pole of the permanent magnet, but, owing to its hysteresis, it will retain a certain amount of magnetism. As it enters the glass tube it commences to come under the weaker influence of the south pole of the magnet, which is tending to make it into a north pole,

but unless disturbed it will retain its original residual magnetism as a south pole.

594. When an oscillating current is induced in the aerial, this current will pass round the single layer winding on the glass tube and allow the magnetism in the iron to be reversed, thus causing a sudden change in the magnetic field, and thereby inducing a momentary current in the secondary coil, to which the telephones are connected.

595. If, on the other hand, no oscillations are received in the aerial, the iron will pass through the primary tube without having its magnetic polarity suddenly changed, and therefore no sound will be produced in the telephones.

596. It will be seen, then, that we have a continuous supply of iron inside the primary tube in such a condition that oscillating currents passing through the coil of wire will cause it to change its polarity suddenly.

597. Experience has shown that the magnetic detector is quite the most reliable and robust form of receiver which has yet been invented, but although extremely sensitive, it is not as sensitive as the modern crystal detectors. Its reliability, however, makes it a valuable instrument as a stand-by, or in places where experienced operators are not obtainable.

598. To tune up the magnetic detector to any desired wave-length, an adjustable inductance and an adjustable condenser are joined in series with the de-magnetising or primary winding of the detector.

599. **No tuning is required for the secondary or telephone winding**, for the currents induced in the secondary are not oscillatory so that normally the

magnetic detector can be regarded as a single-circuit receiver.

600. As this arrangement does not give particularly sharp tuning, an instrument was designed, known as **the Multiple Tuner**, through which the oscillations have to pass before reaching the primary winding of the magnetic detector.

601. The multiple tuner consists of three oscilla-

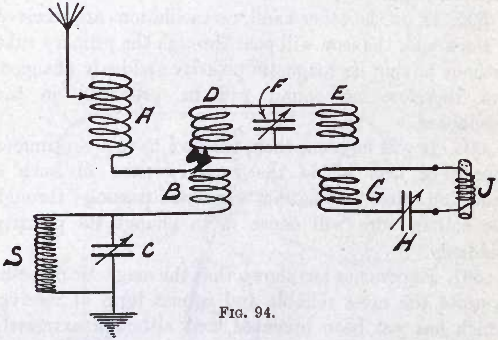


FIG. 94.

tory circuits acting inductively upon each other, each of which is adjustable as regards its wave-length. A diagram of connections of a simple form of this tuner is shown in Fig. 94.

As will be seen from the diagram, there are three distinct circuits, namely, the "aerial" circuit, the "intermediate" circuit, and the "magnetic detector" circuit.

Each of these circuits must be in tune with the wave-length it is desired to receive.

602. The aerial circuit consists of an adjustable inductance A, an inductive winding B, and an adjustable condenser C, all connected in series with one another.

The inductive winding B is so placed that any oscillations in it induce similar oscillations in the intermediate circuit, which consists of two inductive windings D and E, connected in parallel and across an adjustable condenser F.

Any oscillations induced in the winding D will also flow in the winding E, since the two windings are in parallel, and the wave-length of the circuit is adjusted by changing the capacity of the condenser F.

603. The third circuit—the magnetic detector circuit—consists of an inductive winding G, and an adjustable condenser H, and by itself is incomplete, but it is completed by connecting in series with it the primary winding of the magnetic detector as shown by J.

The telephones are connected as described before, across the secondary coil of the magnetic detector

"ATMOSPHERICS"

604. Electric disturbances in the atmosphere which affect the receiving apparatus of wireless telegraph stations are known by the name of "atmospherics."

They produce in the telephones noises which, if strong enough, will drown the signals being received

Where small aerials are being used, these atmospherics are not usually troublesome, but where large and high aerials are employed, if measures were not taken to reduce their effect, it would be impossible, sometimes for days together, to communicate at all.

605. The difficulty in getting rid of "atmospherics"

is that they have no particular tune, but **will cause the aerial circuit to oscillate to its own natural frequency**, so that, no matter to what wave-length the circuit is adjusted, " atmospherics " are still induced in the receiver.

606. One method of avoiding them can be described briefly as follows :

Two receiving circuits are opposed to one another in such a way that if equal effects are produced in each circuit, these effects are neutralised, and therefore produce no sound in the telephones.

If one of these circuits is in tune with the wave-length being received, and the other circuit is out of tune with this wave-length, unequal effects will be produced in the two circuits by the waves, and the signals will be received in the ordinary way.

The " atmospherics," however, as already stated, will affect both circuits equally, so that the effect of the " atmospherics " is neutralised, and they will produce no sound in the telephones.

Although the principle of this method is simple, the application of it to different receivers is extremely complicated, and for this reason we have not described the arrangement in detail.

607. There is another form of " atmospheric " called " static," which is extremely troublesome should a condenser be connected in series with the aerial for the purpose of tuning.

The atmospherics continually charge up this condenser until either the condenser is broken down or the charge sparks across the two sides of the condenser.

608. " Statics," however, can very easily be dealt with by connecting a coil of wire, as shown by S, Fig. 94, from the aerial side of the condenser to earth, which

allows the current to pass through the coil of wire to earth instead of charging up the condenser.

It is, however, necessary that this coil be highly inductive, as otherwise not only would the current caused by the "atmospherics" pass through it, but also the oscillating currents, thereby interfering with the tuning effect of the condenser C.

609. For this reason, in nearly **all receivers that are provided with aerial tuning condensers**, a coil of wire, known as an "inductive shunt," is connected from the "aerial" side of the condenser to earth.

AERIALS

610. The function of an aerial, as we have already shown, is twofold.

In the first place it is required to radiate energy in the form of aether waves from the oscillating currents flowing in it. In this case it may be said to act as a radiator.

In the second place it has to pick up energy in the form of oscillating currents from aether waves which cross it. In this case it may be said to act as an absorber. It is found that any oscillatory circuit which is efficient as a radiator (*vide* paragraph 289) will also act efficiently as an absorber, and for this reason in nearly every case the same aerial is used both for the purpose of transmitting and receiving.

Shape of an Aerial

611. The shape any particular aerial takes will depend upon many practical considerations.

The shape of an aerial can be roughly classified under one of four headings, namely, "Vertical" aerials,

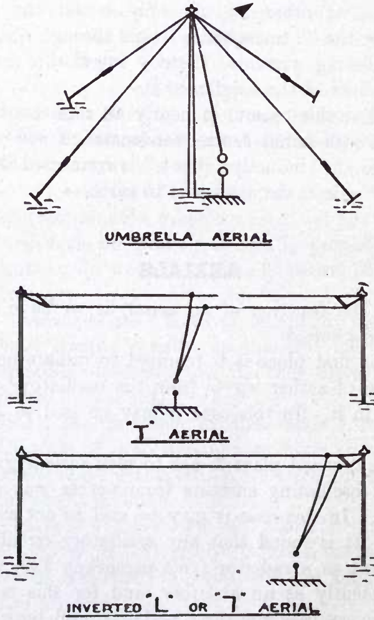


FIG. 95.

"Umbrella" aerials, "T" aerials, and inverted "L" aerials. Fig. 95 represents an example of each of these shapes.

612. For very small portable stations the umbrella

aerial is found to be convenient, principally because it only requires one mast to support it, and the aerial, instead of putting a side stress on the mast as in the case of "T" or inverted "L" aerials, can be made to act as a set of stays, thus assisting to support the mast.

613. The "T" aerial, on the other hand, is used largely on board ship, where in nearly every case two masts are available and the wireless cabin is usually amidships.

614. Sometimes, however, it is more convenient to use the inverted "L" aerial, on account of the position of the wireless cabin. The inverted "L" aerial is used very largely where very long aerials are required, such as in the case of long-distance stations. It is also used largely for military stations of medium size, on account of the fact that it is easy to erect in almost any position. It can, for instance, be as easily erected in a road or street as it can in an open field; thus for military purposes offering a great advantage over the umbrella aerial.

Size of an Aerial

615. The next point to consider is the size of an aerial. This depends chiefly upon the wave-length it is required to transmit, which in turn depends to a large extent upon the power that it is necessary to use.

Every aerial has its own natural wave-length, called its fundamental wave-length, depending upon its own capacity and its own inductance (*vide* paragraph 292 onwards).

616. If we increase the length of an aerial we increase both its capacity and its inductance, and thereby

increase its fundamental wave-length. If we add on to an aerial another parallel wire, we increase the capacity of the aerial, because two capacities in parallel result in a larger capacity, but at the same time we decrease the inductance of the aerial, because two inductances in parallel result in a lower total inductance. Thus it is found that by adding another wire to an aerial its fundamental wave-length remains more or less unaltered.

617. If, however, instead of keeping the additional wire or wires of the aerial parallel with one another we separate them out radially, as in the case of the umbrella aerial, and if the extremities of the radial wires approach the earth, as is usually the case in the umbrella aerial and also in some forms of the "T" aerial, then the capacity of the aerial as a whole is increased more rapidly than the inductance is decreased, because the inductance of the down lead is unaltered, with the result that the fundamental wave-length is increased.

618. In practice it is found that with single-wire aerials or parallel-wire aerials, whose wires run either vertically or horizontally, the wave-length is usually about four and a quarter times the length of the aerial. With a "T" aerial, the upper portion of which is kept horizontal, the fundamental wave-length is about five times the length of the aerial, but if the ends of the wires are brought down so as to approach the earth, the wave-length will be still further increased in proportion to the length of the wire.

619. With an "umbrella" aerial, the wave-length may be as much as eight times the length of the aerial, according to the number of radial wires forming it and the height of their ends from the earth, and the height of the mast.

Thus, it will be seen that two or more aerials, both having exactly the same fundamental wave-length, can have different proportions of capacity and inductance.

620. We have already shown, in paragraph 294, that we can increase the wave-length of the aerial by connecting an inductance in series with it. Further, we can decrease the wave-length of an aerial by connecting a condenser in series with it.

We are, however, limited by practical considerations in the extent to which we can thus increase or decrease the wave-length of an aerial from its fundamental value. The reason for this is that the aerial is most efficient as a radiator, and therefore also as an absorber, when neither inductance nor capacity has been connected in series with it (*vide* paragraph 295).

621. For this reason it is usual to design an aerial so that its fundamental wave-length is approximately that to which it is to be used for transmitting or receiving.

It is found in practice convenient for a station to transmit on only a limited number of wave-lengths, but it is essential that the same station be able to receive over a very large range of wave-lengths, and therefore it is usual to consider only the transmitting requirements when designing the aerial.

622. The construction of an inductance coil, suitable for doubling the wave-length of a given aerial, is far cheaper and also more efficient than a condenser suitable for halving the fundamental wave-length of an aerial, and for this reason the aerial is usually designed to have a fundamental wave-length equal to, or rather shorter than, the shortest wave-length it is required to transmit. There are, of course, exceptions to this rule where special

conditions have to be fulfilled. For the purpose of this book it is unnecessary to deal with them here.

Height of an Aerial

623. The height of an aerial is a very important consideration, because it is found that **the range of a station of a given power is directly proportional to the average height of the aerial.** Thus, if we double the average height of the aerial of a given station, we double the range of that station without increasing the power we have to radiate.

624. It depends, of course, entirely on circumstances whether it is cheaper, or for other reasons more convenient, to increase the height of an aerial or to increase the power of the station in order to increase the range. For portable stations it is obviously convenient to keep the masts as low as possible, and to keep the aerial as simple as possible, for tall masts are not only heavy for carrying about, but take a considerable length of time to erect.

It is found in practice that for stations that are going to be carried about by hand or on horseback, 30 feet is a very convenient height of mast, although, where time taken to erect is not of primary importance, masts 50 feet or even 70 feet high can be conveniently used.

625. Further, the cost of a mast very rapidly increases with its height, and it therefore becomes a question on this account whether it is cheaper to increase the power of the station or to increase the height of the masts.

The Advantage of using Aerials of a Large Capacity

626. The advantage of having a greater capacity in the aerial is very apparent when we try to increase the wave-length by adding an inductance in series with it. Adding an inductance to an aerial reduces its efficiency, and also introduces difficulties of insulation which will be better appreciated after reading paragraph 632 onwards, so the less inductance we have to add to obtain the required wave-length the better.

627. A large-capacity aerial requires less inductance in series with it to increase its wave-length to a given value

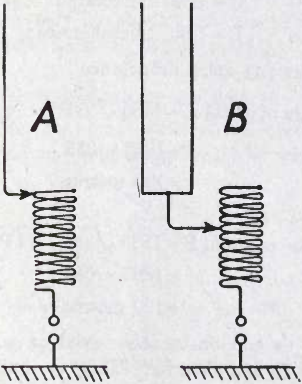


Fig. 96.

than a small-capacity aerial, assuming, of course, that the fundamental wave-lengths of the two aerials are the same.

It is quite easy to show this by the application of the formula given in paragraph 259, namely :

$$\lambda m = 1885 \sqrt{C(mf) \times L(mh)}.$$

We will suppose that the fundamental wave-length of each of the aerials A and B, shown in Fig. 96, is 100 metres, but in the aerial B the capacity is larger, and therefore the inductance is smaller than in the aerial A. We will suppose that in the aerial A

$$C = \cdot 0002 \text{ microfarad}$$
$$L = 14 \cdot 1 \text{ microhenries,}$$

and in the Aerial B

$$C = \cdot 0004 \text{ microfarad}$$
$$L = 7 \cdot 05 \text{ microhenries;}$$

then, without any extra inductance,

$$\lambda m \text{ of aerial A} = 1885 \sqrt{\cdot 0002 \times 14 \cdot 1}$$
$$= 1885 \times \cdot 053$$
$$= 100 \text{ metres,}$$

and also

$$\lambda m \text{ of aerial B} = 1885 \sqrt{\cdot 0004 \times 7 \cdot 05}$$
$$= 1885 \times \cdot 053$$
$$= 100 \text{ metres.}$$

Now let us add on to each aerial an additional inductance of 10 microhenries. Then we shall have—

$$\lambda m \text{ of aerial A} = 1885 \sqrt{\cdot 0002 \times 24 \cdot 1}$$
$$= 1885 \times \cdot 0695$$
$$= 131 \text{ metres (about);}$$

but

$$\lambda m \text{ of aerial B} = 1885\sqrt{\cdot 0004 \times 17\cdot 05}$$
$$= 1885 \times 0\cdot 826$$
$$= 156 \text{ metres (nearly).}$$

628. It will be seen that with the same additional inductance we have increased the wave-length of the aerial B from 100 metres to 156 metres, while we have only increased the wave-length of the aerial A from 100 metres to 131 metres.

Thus, if we wished to increase the wave-length of the aerials shown in Fig. 96 from 425 feet to, say, 600 feet, we should find that perhaps 10 turns of an inductance coil would be required in the case of the aerial A, while only about six turns would be required in the case of the aerial B, as illustrated.

The Length of an Aerial

629. The length of an aerial is not necessarily the total length of wire, but is the length of wire from the

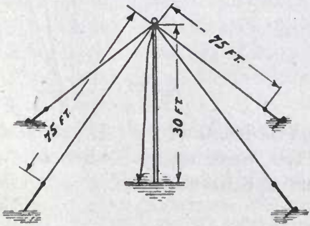


Fig. 97.

point where it is connected to the instruments to any one of its extremities. Thus in the "umbrella" aerial

shown in Fig. 97 the length of the aerial is 105 feet, made up of 30 feet of " down-lead " and 75 feet of radial wires.

630. The length of the " T " aerial shown in Fig. 98 is 150 feet, made up by 50 feet of " down-lead " and 100 feet of horizontal wire in a 200-foot span.

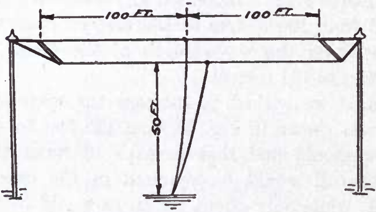


FIG. 98.

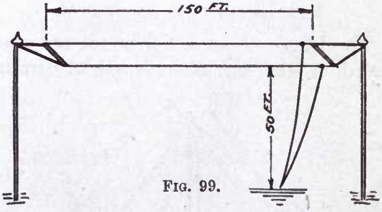


FIG. 99.

631. And the length of the " L " aerial shown in Fig. 99 is 200 feet, made up by 50 feet of " down-lead " and 150 feet of horizontal wire.

DISTRIBUTION OF POTENTIAL AND CURRENT ALONG AERIALS

632. Before going into the question of the construction and insulation of aerials, let us first consider how the voltage of the aerial is distributed when oscillating currents are flowing in it.

633. Taking the case of an aerial directly energised by an induction coil, *i.e.* "plain aerial," the maximum initial voltage to which the aerial is charged will depend, as we have shown, upon the voltage applied across the spark-gap by the induction coil. This voltage can be regulated by increasing or decreasing the length of the spark-gap.

634. (The voltage required to jump an air-gap where points are used for the electrodes is about 12,000 volts for each centimetre length of air-gap. If knobs or balls are used for electrodes, the voltage required will be increased to an extent depending upon the curvature of the ball. Thus, using balls one inch in diameter, it is found that a voltage of approximately 30,000 volts for each centimetre length of air-gap is required.)

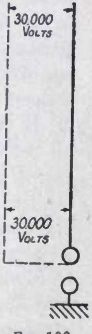


Fig. 100.

635. Assuming for the sake of explanation that we are using ball electrodes set one centimetre apart, then at the instant immediately before the gap is broken down the whole aerial is charged up to a **uniform** potential of 30,000 volts. In this case the distribution of the voltage along the aerial wire can be shown diagrammatically, as in Fig. 100, by a dotted line drawn parallel

with the aerial at a distance from it representing 30,000 volts.

636. Now the energy stored up in a condenser can be regarded as "potential" energy, as opposed to the "kinetic" energy which is stored up in an inductance through which a current is flowing; just as the mechanical energy stored up in a compressed spring is in the form of "potential" energy as opposed to the "kinetic" energy which is stored up in a revolving fly-wheel or in any **moving** body.

637. In all periodic oscillations, whether mechanical or electrical, the energy is continually changing from the one form to the other. Thus, for example, in the case of a vibrator, as shown in Fig. 37, which is made to vibrate between the positions W_1 and W_2, when it occupies one or other of these extreme positions, it is for the moment at rest and all the energy is then in the form of "potential" energy stored up in the tension of the spring blade. On the other hand, when it occupies the position W, there is for the moment no tension in the spring, but at this moment the weight W is travelling at its maximum speed, consequently all the energy is then in the form of "kinetic" energy stored up in the moving body W At intermediate positions obviously part of the energy is stored up in the tension of the spring and part of it in the moving weight W

Similarly, in the case we are now considering, namely, that of an oscillatory circuit, the energy at one instant is all stored up in the condenser in the form of "potential" energy, and at this moment the electricity is at rest, that is to say, there is no current flowing. At the next instant when the condenser is fully discharged and

before it commences to be charged in the opposite direction, the current flowing in the circuit is at its maximum, and all the energy is then in the form of "kinetic" energy stored up in the current flowing through the inductance of the circuit. Thus it will be seen that the total energy in an aerial or other oscillatory circuit at any moment is the sum of the "potential" energy and the "kinetic" energy.

638. In paragraph 285, we showed how the energy stored up in a **condenser** at any moment could be determined from the equation $E = \frac{1}{2}CV^2$, where C is the capacity of the condenser; and V the E.M.F. to which it is charged.

Taking the analogous mechanical case of energy stored up in a compressed spring, it can be shown that at any moment the energy $E = \frac{1}{2}(F)T^2$, where (F) is the flexibility [1] of the spring, and T the tension to which it is stressed.

639. Now the energy stored up in a moving body, *i.e.* the "kinetic" energy, depends upon the weight of that body and the speed at which it is travelling. The energy is directly proportional to the weight of the moving body and proportional to the square of the speed at which it is travelling. If M is taken to represent the mass of the body and V to represent its velocity, then it can be shown that energy stored up in it at any moment $E = \frac{1}{2}MV^2$.

640. Similarly, in an electrical circuit the energy stored up in the inductance L of the circuit through

[1] Note the term flexibility is used for the sake of simplicity, and the equation will be found correct if F is taken equal to $\frac{L}{E}$, where L is the elongation of the spring, and E is the modulus of elasticity.

which a current is flowing, is directly proportional to the inductance and proportional to the square of the current flowing through that inductance. If J = energy in joules, L = inductance in henries, and I = current in amperes, it can be shown that $J = \frac{1}{2}LI^2$.

641. Returning to the particular case we are considering, namely, that of an aerial which is uniformly charged to a pressure of 30,000 volts, then it is evident that at the moment before the spark-gap is broken down, all the energy is stored as "potential" energy, because at this moment there is no current flowing; therefore if C is the capacity of the aerial, and V the voltage to which it is charged, $J = \frac{1}{2}CV^2$.

At the next instant the gap is broken down, and the "potential" energy in the charged aerial is gradually transferred to "kinetic" energy in the form of a current of electricity passing through the inductance of the aerial to earth.

642. If L represents the inductance of the aerial, and I represents the current flowing through that inductance, and J again represents the energy in the aerial, then, when the current is oscillating, the energy in the aerial **at any instant** $= \frac{1}{2}C(V)^2 + \frac{1}{2}L(I)^2$.

643. Taking the instant when one-quarter of an oscillation has taken place, the voltage of the aerial has become zero, and therefore $\frac{1}{2}CV^2 = 0$. At this instant, therefore, the whole of the energy is transferred to the current flowing through the inductance and will then equal $\frac{1}{2}LI^2$, and consequently the current in the aerial is at its maximum.

Similarly, taking the instant when one-half oscillation has taken place, the current has become zero, and therefore at this instant the whole of the energy is

transferred to the charge in the capacity of the aerial, and will then equal $\frac{1}{2}CV^2$, and consequently the voltage of the aerial is at its maximum.

644. Assuming, for the moment, that none of the energy is lost either in radiation or resistance, then the energy in the aerial will be the same at the end of the first oscillation as it was originally at the moment immediately before a spark occurred, but since the spark-gap is now broken down the bottom end of the aerial must be considered as connected to earth, and therefore the voltage at this point will remain at zero while the maximum voltage will be found at the free end of the aerial. Thus, it will be seen that the distribution of voltage over the length of the aerial will take a different form from that shown in Fig. 100. It will take the form of the curve shown in Fig. 101.

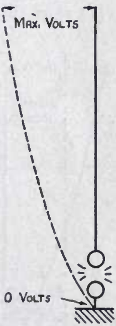


FIG. 101.

At first sight it would appear that the maximum value of the voltage obtained at the free end of the aerial would be the voltage to which it was originally charged. This, however, is not the case, for the following reason.

645. At the moment when the aerial is first charged, the charge is uniformly distributed over the whole of the aerial, as shown in Fig. 100, and since the capacity of the aerial is also distributed over the whole of the aerial, it follows that the whole of the capacity of the aerial is charged to an equal voltage.

646. On the other hand, after the first oscillation when the charge in the aerial is distributed, as shown in Fig. 101, the whole of the capacity in the aerial

is not charged to the same voltage, and therefore the free end of the aerial must necessarily become charged to a higher voltage than originally, in order that the aerial may store up the same amount of energy as before.

647. It can be shown mathematically that the voltage at the free end of the aerial at the end of a complete oscillation will be $\sqrt{2}$ times, or approximately 1·414 times the voltage to which it was originally charged, assuming (1) that the voltage is then distributed in the form of a sine curve, and (2) that no energy has been lost or radiated during the oscillation. This will be readily understood by referring to Figs. 102 and 103.

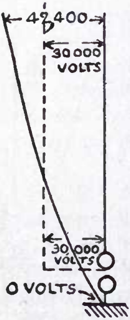


FIG. 102.

648. Fig. 102 shows the relative distribution of the voltage along the aerial wire, the dotted line showing the original charge put into the aerial by the induction coil, and the full line showing the charge in the aerial at the end of the first oscillation.

649. Fig. 103 shows the variation of voltage at the free end of the aerial wire during the first oscillation. Up to the point A the curve shows the comparatively slow rise of voltage, while the aerial is being uniformly charged up by the induction coil to a value of 30,000 volts. At the point A the spark-gap breaks down, and oscillations commence, and the voltage at the end of the aerial first drops to zero at the moment B when the aerial is discharged and then rises to a value $\sqrt{2}$ times the original charge = about 42,400 volts.

650. We have said that the energy stored up in the

aerial when the whole of the charge is in the aerial $= \frac{1}{2}CV^2$ This is only true when the whole of the capacity of the

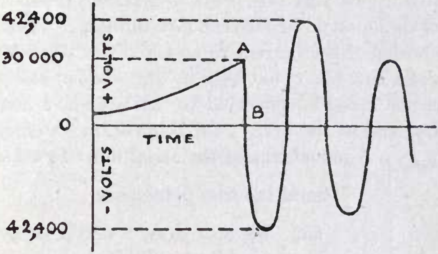


FIG. 103.

aerial is uniformly charged to the voltage V. When the aerial is oscillating, the **effective capacity of the aerial must be taken as $\frac{\pi}{2}$ times the true capacity.**

DISTRIBUTION OF CURRENT IN AN AERIAL

651. We have already explained in paragraph 643, that at the moment when the voltage at the end of the aerial is at its maximum, the current flowing into the aerial is at zero, and the distribution of the voltage along the aerial when the latter is oscillating to its fundamental wave-length is such that there is a *node of potential* where the aerial is connected to earth, and an *anti-node of potential* at the free end of the aerial. *The distribution of the current is the reverse of this.*

It is obvious that the maximum current will flow at the earth end of the aerial, for all of the current which flows into the aerial must necessarily pass this point,

whereas, taking a point half-way up the aerial, only that current which is required to charge the upper half of the aerial will flow past this point, and taking the extreme end of the aerial no current can flow through it. Thus the distribution of the current in an aerial will also take the form of a sine curve, but with its anti-node at the point where the aerial is connected to earth, and its node at the free end of the aerial; for this reason the **effective inductance of the aerial must be taken as $\frac{2}{\pi}$ times the true inductance.**

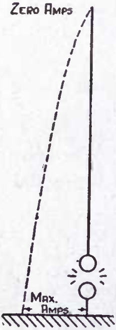


Fig. 104.

652. We may draw a curve, as shown by the dotted line in Fig. 104, representing the distribution of the current flowing along an aerial, where the distance between the curve and the full line representing the aerial wire represents the comparative amount of current flowing. This current will vary from a maximum value when the potential of the aerial is at zero, to zero when the potential of the aerial is at its maximum, but the distribution of the current along the aerial will be always in the same proportion, so that although the amplitude of the curve will vary, the form of the curve will remain the same.

Effect on Current and Voltage Distribution of Connecting an Inductance or Capacity in Series with an Aerial.

653. It is evident that whatever form the distribution of the voltage along an aerial takes, the distribution

of the current *will always take a relative form, but with its node at the point where the voltage is at its maximum, and* vice versa, *with its anti-node at the point where there is a voltage node.* In describing further effects, therefore, it will be sufficient only to indicate the distribution of the voltage along different aerials.

654. When an inductance is connected in series with an aerial, the distribution of voltage along the aerial when oscillating is similar to that already described for a simple aerial, except that the inductance must be regarded as a continuation of the aerial, and therefore the voltage increases along the inductance as well as along the aerial, as shown in Fig. 105; thus the greater the inductance that is connected in series with an aerial, the higher will be the voltage across that inductance when it is oscillating.

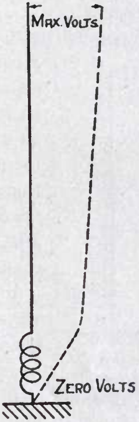


FIG. 105.

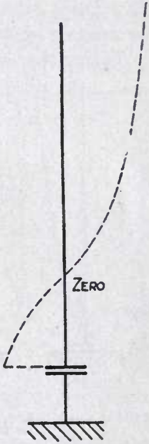


FIG. 106.

655. It is most important to bear this point in mind when designing inductance coils to be used for transmitting purposes, for the coil must be very highly insulated from earth at the end which is connected to the aerial, and, further, when there is a large amount of inductance connected in series with the aerial, very high insulation

must be provided where the aerial wire enters the building.

656. The effect on the distribution of the voltage, of connecting a condenser in series with an aerial, is to create a node of potential in the aerial at some point above the condenser, as shown in Fig. 106.

657. *The exact position of the node will depend upon the relative values of the capacity of the condenser, and the capacity of the aerial.*

Taking the two possible extreme values of capacity of a condenser, we find that if an infinitely large capacity be connected in series with an aerial, the node will be found exactly at the junction of the aerial and the condenser, as shown in Fig. 107, for an infinitely large capacity is equivalent to a direct connection to earth. On the other hand, if we connect an infinitely small capacity in series with an aerial, the node of potential will occur exactly half-way up the aerial, as shown in Fig. 108.

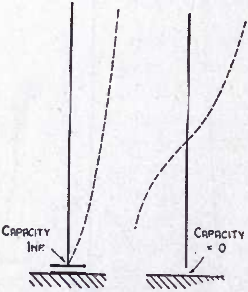


FIG. 107. FIG. 108.

658. Thus any intermediate capacity between the values of infinity and 0 will create a node somewhere between the bottom of the aerial and half-way up the aerial, according to the relative values of the capacity of the aerial and the capacity of the condenser.

Harmonics

659. Any oscillatory circuit in which the capacity and inductance are distributed, that is to say, any "open" oscillatory circuit, will oscillate to **harmonics** of the fundamental wave.

The first harmonic has a frequency of three times the fundamental frequency, the second harmonic five times, and the third harmonic seven times, and so on. Thus the wave-length of the first harmonic will be one-third the fundamental wave-length, that of the second harmonic one-fifth, and that of the third one-seventh.

660. When the aerial is oscillating to the first harmonic the distribution of the voltage along it will take the form shown in Fig. 110, from which it will be seen that there are two points on the aerial, of maximum voltage, one at the end of the aerial and the other a third of the way up the aerial. Further, a node of voltage is obtained at a point two-thirds of the way up the aerial, as well as at the point where the aerial is connected to earth.

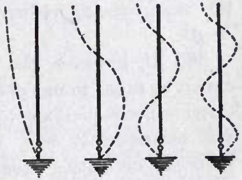


Fig. 109. Fig. 110. Fig. 111. Fig. 112.

The distribution of voltage along an aerial oscillating to its fundamental, its first harmonic, second harmonic, and third harmonic, is shown diagrammatically in Figs. 109, 110, 111, and 112 respectively.

661. These harmonics can be distinctly detected with a sensitive wavemeter when an aerial is excited as "plain aerial." It will be noticed, however, that the funda-

mental wave-length gives by far the strongest effect in the wavemeter. The first harmonic will be very much stronger than the second, and the second harmonic stronger than the third, and so on. Difficulty will be found in detecting any of the higher harmonics on account of their weakness.

662. When an aerial is directly excited, as, for instance, by means of an induction coil, the harmonics are only feebly produced, and when an aerial is excited indirectly by a coupled "closed" oscillatory circuit which is tuned to the fundamental wave-length of the aerial, the harmonic wave-lengths of the aerial will be even more feebly produced, practically all of the energy being radiated in the fundamental wave-length.

663. If, however, the coupled "closed" oscillatory circuit **be tuned to one of the harmonics** of the aerial, the aerial will not oscillate to its fundamental wave-length, and consequently only the harmonic to which the "closed" oscillating circuit is tuned will be radiated. As a matter of fact, an aerial excited to one of its harmonics will radiate more rapidly than when excited to its fundamental wave-length. Use is therefore sometimes made of this phenomenon to avoid the necessity of inserting a condenser or a large inductance in series with the aerial, thus reducing its efficiency as a radiator, when a station is required to transmit a long wave-length and a short wave-length on the same aerial, and where it is possible to arrange that the short wave-length is a harmonic of the long wave-length.

664. In the early days of wireless telegraphy, all ships fitted with wireless could transmit on either of two wave-lengths, which were called respectively "Tune A"

and "Tune B." Tune A was a wave-length of 360 feet, and Tune B was a wave-length of 1080 feet. Thus it was usually arranged that the wave-length of the aerial was approximately 1080 feet, and that the primary circuit of Tune A was tuned to the first harmonic of this aerial, namely, 360 feet, and that of Tune B to the fundamental.

It is, however, not possible to arrange this now, for the International Convention of Radio-Telegraphy have laid down that all ships must be able to transmit wave-lengths of either 600 metres or 300 metres, and in this case the lower wave-length is not a harmonic of the higher wave-length.

MASTS

665. In paragraph 623, we pointed out that the range over which a given transmitter can communicate, is approximately proportional to the height of the aerial. It is obvious, therefore, that where range of communication is of paramount importance, the masts used for supporting the aerial should be as high as practical consideration will allow.

The masts of permanent Land Stations are usually erected by experienced engineers and riggers, and skilled men are usually available for keeping the masts in good repair, but the masts used on portable stations are frequently handled by men who have had no such experience, and we therefore think that a few remarks on the subject will be useful.

STRAIN ON MASTS

666. A mast will withstand a very much greater

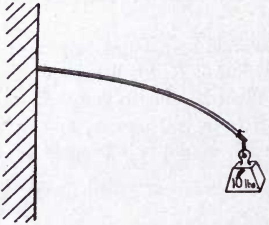


FIG. 113.

FIG. 114.

stress acting straight down its length than it will one acting at right angles to its length.

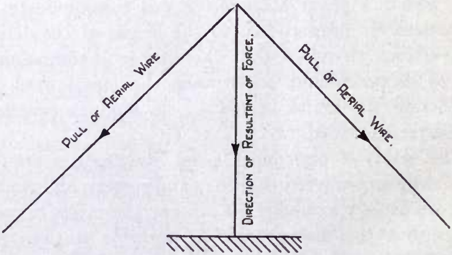


FIG. 115.

A simple experiment with a stick about $\frac{1}{4}$ inch diameter by 5 feet long will readily illustrate this point. If we exert a pull of say 10 lb. on one end of the stick

in a direction at right angles to its length, as shown in Fig. 113, the stick will probably break, or at all events bend very sharply. If, however, we exert the same force on the end of the stick in a direction in line with its length, as shown in Fig. 114, the stick will withstand it easily.

667. In the case of a mast supporting an umbrella aerial, as shown in Fig. 115, the result of all the forces exerted by the wires is a force acting straight down the length of the mast, and therefore the best advantage is being made of the strength of the mast.

668. But in the case of a mast supporting a horizontal aerial, as shown in Fig. 116, where the aerial is attached to the top of the mast, the force exerted by the aerial is at right angles to the length of the mast, and therefore the strength of the mast is not being used to the best advantage.

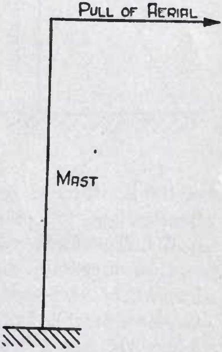


FIG. 116.

669. If, however, we attach a stay to the top of the mast, and connect the stay to a point on the ground some distance from the foot of the mast, as shown in Fig. 117, the pull of the aerial will be carried by the pull of the stay, and the resultant of the two forces—*i.e.* of the force exerted by the aerial in one direction, and the force exerted by the stay in another direction—is a force acting straight down the length of the mast.

670. A very simple way of calculating the amount of the force acting on the stay and that acting on the mast is by drawing a parallelogram, as shown in Fig. 118.

Assuming that the aerial is exerting a horizontal pull of 200 lb., and we take 1 inch to represent a pull

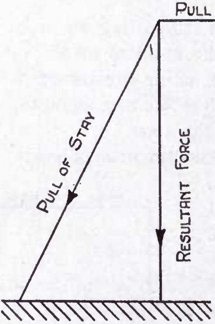


FIG. 117.

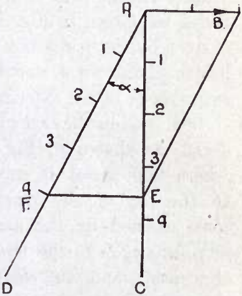


FIG. 118.

of 100 lb., then we may set out a horizontal line, AB, 2 inches long, to represent the pull of the aerial.

671. The force exerted by the mast will be in a vertical direction; therefore we may set out a vertical line, AC, of indefinite length, representing the direction of the force exerted by the mast. Further, we may draw a line, AD, representing the direction of the force exerted by the stay, the angle α the same as the angle formed by the stay and the mast.

If now we draw from the point B a line parallel with the line AD, this line will cut the line AC at the point E, and the length of the line EA in inches will represent the force exerted on the mast in hundreds of pounds.

Further, if we draw from the point E a line parallel with the line BA, this line will cut the line AD at the point F, and the length of the line AF in inches will likewise represent the force in hundreds of pounds exerted by the stay.

672. Measuring these lines in the particular case

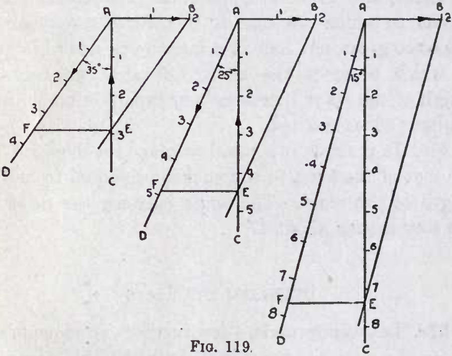


FIG. 119.

shown in Fig. 118, where the angle between the mast and the stays is 30°, we find that the line AE is about $3\frac{1}{2}$ inches long, and therefore the force required to be exerted by the mast, or the pressure on the mast, is 350 lb., while the line AF is about 4 inches long, and therefore the force required to be exerted by the stay, or the pull on the stay, is 400 lb.

673. By making similar diagrams for various angles between the mast and the stay, as shown in Fig. 119, it will be seen that the greater the angle the less the strain both on the mast and on the stay for a given aerial pull.

674. Obviously, then, *it is an advantage to increase the angle at which we stay a mast*, more especially in the case of portable masts, where anchor pegs have to be used for attaching the stays to the ground, and in soft ground a comparatively small pull would be required to pull them out of the ground.

There are, of course, practical limitations to the extent to which we can do this, for if we make the angle too great, not only is a large open space required in which to erect the mast, but also the necessary length of the stays increases very rapidly after an angle of about 30° is reached.

675. In practice it is usual to make the distance from the foot of the mast to the anchor peg equal to half the length of the mast. The angle between the mast and the stay is then about 27°.

Buckling of Masts

676. Let us now make a few further experiments with the thin stick described in paragraph 666. If we take two such sticks of exactly the same diameter and length, one of which is perfectly straight and the other very slightly curved, as shown in Fig. 120, it will be found that the straight stick will carry a far greater weight than the bent stick. If we increase the weight on the bent stick gradually, and carefully watch the effect, it will be seen that the bend increases gradually as the weight is increased, until it reaches a certain critical

Fig. 120.

bend, depending upon the nature of the wood of which the stick is made. As soon as this critical point is reached, a small increase in the weight will cause the stick to collapse and break.

We will suppose, for the purpose of explanation, that this critical point is reached when the weight applied is 20 lb., and that 21 lb. is necessary to break the stick.

677. If now we apply a weight of 21 lb. to the straight stick, it will be found that it carries the weight without any sign of breaking. If, however, we apply a side pressure in the middle sufficient to start a slight bend, the stick will immediately collapse in exactly the same way as the other stick. Only a very slight side pressure is required to start the bend or " buckle." In the case of a mast in the open, the pressure of the wind will be found quite sufficient to start a buckle ; but in any case, all masts made up of a number of loose sections will have a slight bend in them to start with, owing to the play between the plugs and sockets.

678. If now we take the same sticks and cut down their length by one half, it will be found that exactly the same effects will be produced by applying pressure to the ends, except that it will now take four times the weight to reach the critical point.

679. In practice it is found that *the weight a given stick or mast will carry is inversely proportional to the square of its length.* By staying the middle of a stick or mast in such a way that the point of attachment of the stays to the mast cannot move sideways, as shown in Fig. 121, we have in effect converted the stick into two sticks, each of half the length, one on top of the other. Thus, *by staying a stick or mast in the middle, we quadruple the weight or pressure it will carry*

Mast Stays

680. The material of which the stays are made depends entirely upon circumstances. For portable masts the stays must be very flexible, as they have to be coiled up on to drums when the mast is dismantled.

681. For masts up to 30 feet in height, rope stays are the most suitable. For masts higher than 30 feet, however, it is better to use metal stays, because rope shrinks

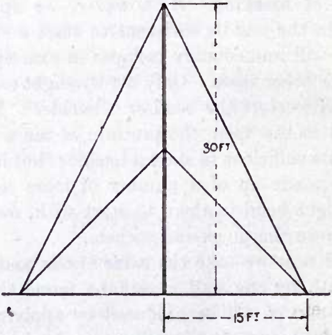


Fig. 121.

badly when it is wet and stretches again when dry, the result being that if a mast has been erected when everything is dry a shower of rain will shrink a long stay sufficiently to pull an anchor peg out of the ground and allow the mast to fall. If, on the other hand, the stays are adjusted when they are wet, they will stretch as they get dry and allow the mast to buckle badly and perhaps break.

682. For long stays, then, metal should always be

used, and for portable masts phosphor bronze is found to be the best metal for the purpose, although somewhat expensive, although it has not the same tensile strength as steel, and will not corrode or rust when exposed to the atmosphere Steel can, of course, be galvanised to stop rusting, but this reduces its strength very considerably, more especially in the case of finely

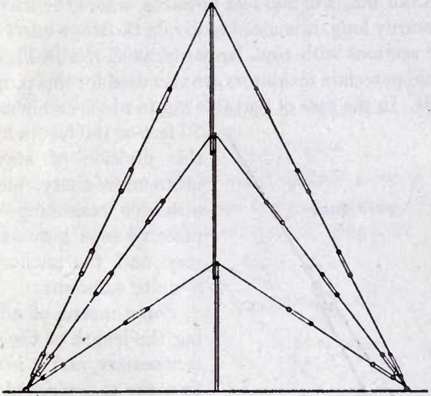


FIG 122

stranded wires. In order to make the metal stays flexible they are made up of many strands of fine wire

683. *When metal stays are used they must be carefully insulated from the earth,* otherwise oscillatory currents will be induced in them on account of their proximity to the aerial, and they would thus absorb a large proportion of the transmitted energy, and thereby reduce the range of the station.

The insulation of stays does not, however, require

to be of a very high order, a short length of rope being in most cases quite sufficient; for even when wet its resistance will be sufficiently high to stop any oscillatory currents in the stays. Although in this case there will be a certain amount of leakage to earth, the energy thus absorbed would not be sufficient to affect the efficiency of the station to any appreciable extent.

In tall masts of 200 feet upwards, where the stays are necessarily long, it is usual to divide the stays into two or more sections with rope lanyards, as shown in Fig. 122. Special porcelain insulators are also used for this purpose.

684. In the case of portable masts which rarely exceed 70 feet or 100 feet in height this division of stays is quite unnecessary, and an insulator consisting of a piece of rope between the stay and the anchor peg is quite sufficient.

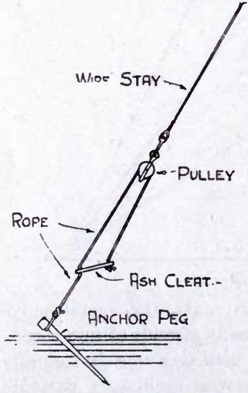


Fig. 123.

Some means of adjusting the length of the stays is necessary, and it is usual to make this piece of rope serve the two purposes of insulating the stay and providing a means of adjusting its length, as shown in Fig. 123.

685. In the case of wooden masts no insulation is necessary at the upper end of the stay, but *in the case of steel masts the insulation of the stay from the mast is even more important than the insulation of the stay from the ground.* The reason

for this is obvious by glancing at Fig. 124, when it will be seen that unless the stays are insulated at the points marked "A," the stays, together with the mast, form a fair-sized umbrella aerial, connected to earth through the mast; the stays forming the radial wires of the aerial and the mast forming the down-lead. This would absorb a very large amount of the energy radiated from the aerial proper.

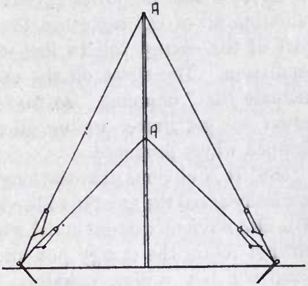


Fig. 124.

686. In the case of steel masts, therefore, it is necessary to insert insulators between the mast and the stay. For portable masts a length of about 6 inches of rope serves the purpose very well, as shown in Fig. 125.

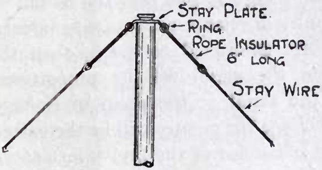


Fig. 125.

THE INSULATION OF AERIALS

687. The insulation of the aerial is a matter of the utmost importance.

Bad insulation means a leakage of current and therefore a loss of power. That is to say, instead of radiating all of the energy in the form of ether waves, part of the energy will be lost in leakage during each oscillation. The effect on the oscillating current is to increase the "damping," so that in addition to loss of power we get flatter tuning, due to the more highly damped waves produced.

688. It is obvious that the longer the energy remains in a leaky aerial the greater will be the loss due to leakage. It is also obvious that an aerial which is a good radiator will not retain the energy put into it for so long as an aerial which is a slow radiator. It follows, therefore, that the slower an aerial radiates its energy the greater the loss of energy due to bad insulation.

689. In addition to the rate at which an aerial radiates, there is another point to be considered, namely, the rate at which the energy is put into the aerial. Assuming that the faulty insulator acts as a conductor with a high resistance connected to earth, then the rate of leakage from the aerial will be proportional to the voltage of the aerial at the point of leakage, for the higher the voltage the greater will be the current passing through the resistance of the faulty insulator.

690. Taking the case of a transmitter in which a primary circuit is loosely coupled to the aerial circuit, the energy in the primary circuit is only slowly transferred to the aerial, so that the aerial will not attain its maximum voltage until, perhaps, the third or fourth oscillation. But since, during these oscillations, the aerial is radiating its energy, it follows that the maximum voltage it will attain will not be so high as if the two circuits were so closely coupled together that the whole of the energy

were transferred to the aerial during the first oscillation. Consequently the loss of energy due to leakage will be less in the case of the loosely coupled circuits than in the case of the closely coupled circuits.

691. Although faulty insulation is bad even in the case of loosely coupled circuits, inasmuch as it results in less power being radiated, it will not put the station completely out of action, for oscillatory currents will still be induced in the aerial, and therefore waves will be radiated, though the range of communication may be very much reduced. This is one of the reasons that give coupled transmitters such a great advantage over "plain aerial." In the case of a plain-aerial transmitter, as the rise in voltage across the secondary of an induction coil, when the primary circuit of the coil is interrupted, takes an appreciable length of time, *the charge in the aerial may leak away through the faulty insulators as fast as it is supplied by the induction coil*, with the result that it is impossible to get a spark across the electrodes from aerial to earth. And, since the current in the aerial is not oscillatory, until the spark takes place, no oscillating currents are produced, and therefore the aerial, under these conditions, does not radiate at all.

Aerial Insulators

692. The first point to consider in connection with aerial insulators is the dielectric strength of the material of which the insulator is made.

693. When an electric pressure is applied to an insulating material or dielectric, a mechanical stress is set up in the dielectric. Further, if the electric pressure is increased beyond a certain limit (depending upon the

thickness and nature of the material), the dielectric is broken or punctured at its weakest point. If the dielectric be a liquid or a gas, the puncture is only momentary and heals up automatically as soon as the current ceases to flow through the path thus made, but in the case of solids the puncture remains, and the insulation is permanently broken down at this point. The voltage at which the puncture takes place for a given thickness of material is called the dielectric strength of the insulating material, and varies considerably with different materials.

694. The following table shows the comparative values of different substances in this respect.

Substance.	Voltage required to puncture 1 centimetre thickness of material.
Air	30,000
Oil	60,000 to 80,000
Ebonite (best quality) . .	500,000
Soft india-rubber . . .	450,000
Mica	1,000,000
Glass	250,000
Paraffin wax . . .	170,000
Porcelain	100,000

The above figures are only approximate and vary considerably with different samples of the same material. In any case, in practice it is advisable to allow a factor of safety of at least 3, usually more.

695. The second point to consider in connection with aerial insulators is the surface insulation. Even when an insulator is perfectly dry, at high voltages electricity will creep over the surface far more readily than it will spark across an air-gap. Thus, if a pressure of 30,000 volts be applied across two metal discs separated by

1·5 cms of air, as shown in Fig 126, no discharge will take place between them, but if the same space be filled with ebonite as shown in Fig 127, although the ebonite will not be punctured (see table of dielectric strengths in paragraph 694), the electricity will run along the surface of the ebonite between the two electrodes.

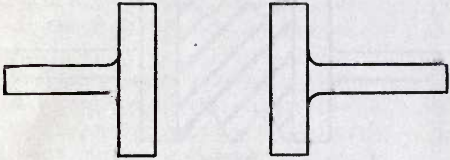


FIG 126

696 In order to increase the length of the path along the surface of the insulator without increasing the overall length of the insulator, it is usual to make the surface

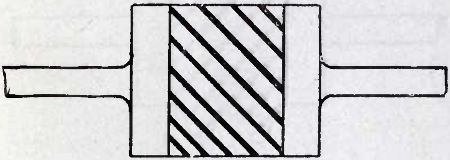


FIG 127

corrugated, as shown in Figs. 128 and 129, thereby doubling or trebling the length of the surface.

In the case of aerial insulators, however, the overall length is not a matter of great importance, so that corrugated insulators are not often used, the insulators being made sufficiently long in themselves.

697 The actual length of surface insulation to allow is a difficult matter to determine, as everything depends upon the nature and condition of the surface. Where

a dry, clean surface is assured at all times, it will be quite safe to allow 4 cms of surface to every 30,000 volts of potential. But aerial insulators are exposed to all kinds of weather conditions, and if the surface of an insulator be allowed to get coated with a film of moisture

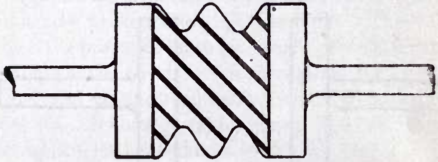


FIG 128

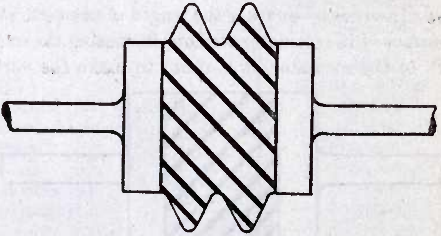


FIG 129.

and dirt, almost any length will be useless for the purpose of insulation.

698. In most cases dirt accumulates slowly, and trouble from this source can be avoided by a periodic inspection and cleaning of the insulators The chief difficulty, therefore, is how to keep the surface of the insulator dry. When the insulator occupies a more or less vertical position this is easily accomplished by fitting a cone over the insulator to act as a water-shed, as shown in

Fig. 130; but when the insulator occupies a horizontal position, as it might, for example, when supporting a horizontal aerial, this method would obviously be useless. In such cases it is usual to make the insulator of ample length and to paint its surface with a bitumastic varnish, so that any moisture settling on it will detach itself into separate drops instead of forming a continuous film of moisture over the whole of the surface.

Fig. 130.

699. The surface of a porcelain insulator has this property without being varnished, but this material is, unfortunately, extremely brittle and therefore unsuitable, at all events for portable stations.

700. An important point to bear in mind when insulating an aerial is to use as few insulators in parallel as possible, for each insulator thus used increases the total

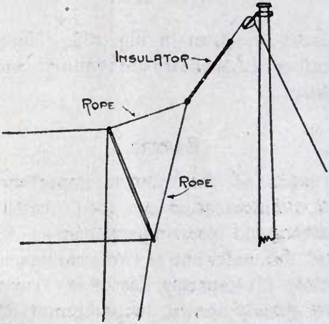


Fig. 131.

leakage from the aerial. Thus an aerial insulated as illustrated in Fig. 131 will only have half the leakage as

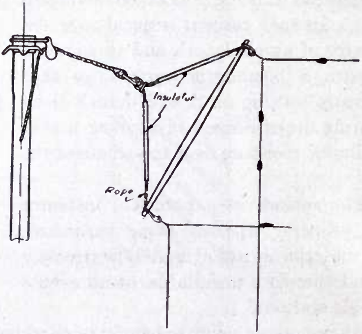


FIG. 132

when insulated as shown in Fig. 132. Moreover, only half the number of insulators are required, and therefore it is less costly.

EARTHS

701. A point of the utmost importance to the efficiency of communication is a good " earth " at both the transmitting and receiving stations.

" Earths " fall under one of two headings, namely, (1) Direct Earths ; (2) Capacity Earths or " counterpoise."

We have already shown, in paragraph 651, that a node of current exists at the free end of the aerial, and that a maximum of current flows at the earthed end of the aerial. This current must flow through the earth connection from the aerial to the earth, and from

the earth to the aerial. Therefore, any resistance in the earth connection will cause loss of power and damping of the oscillations.

702. In the case of ship stations the " earth " is a simple matter, as salt water is an excellent conductor of electricity, and it is therefore only necessary to attach a conducting wire to the metal hull of the ship. In the case of land stations, it is usual to bury a number of plates of zinc, or other non-corrosive metal, at a sufficient depth to ensure their being surrounded by damp earth.

703. It is found better to use a number of long strips spreading radially under the soil than to use one large plate, as the former gives less resistance than the latter. The reason for this is that the effective resistance of a buried " earth " is reduced in proportion to the capacity of the earth plates. Thus, the greater the capacity of the earth plates as a whole the less the effective resistance of the " earth." The most efficient earth, where the resistance of the soil is high, is made by burying a large number of wires below the aerial or burying them radially in all directions, like an underground umbrella aerial.

704. It is not necessary, however, to have a direct electrical connection with the earth: What are known as " counterpoise " or " capacity earths " are frequently used even with comparatively high-power stations. Such an " earth " usually consists of a large number of wires suspended above the surface of the ground and carefully insulated from it. It is important in this case that the capacity of the counterpoise should be at least equal to that of the aerial.

705. For portable stations this form of " earth " is frequently employed, as it takes less time to erect than

it does to dig deep trenches. For such stations, perhaps the most convenient form of earth is a number of long narrow strips of wire-netting, which can be laid on the ground star shaped, and can be rolled up into convenient rolls for transport purposes. Under some conditions, when the surface of the ground is wet and conducting, the "earth" acts as a direct connection to earth, while under other conditions, when the surface of the ground is dry, the "earth" acts as a counterpoise.

706. This form of earth, although not as efficient under some conditions as a true counterpoise, has the great advantage of simplicity and ease of erection, and moreover does not interfere with the approach to the station. It will be readily understood that a number of wires suspended a short distance from the earth over a wide area round a station would be extremely inconvenient in a military camp, where a stray horse might easily become entangled with it at night, and perhaps do serious damage both to itself and the station.

INDEX

P

THE END